RUDIMENTARY TREATISE ON GALVANISM,

AND

THE GENERAL PRINCIPLES

OF

ANIMAL AND VOLTAIC ELECTRICITY,

WITH

BRIEF NOTICES OF THE PURPOSES TO WHICH IT
HAS BEEN APPLIED.

BY

SIR WILLIAM SNOW HARRIS, F.R.S., &c.,
Author of Rudimentary Treatises on Electricity and Magnetism
in this Series.

WITH NUMEROUS ILLUSTRATIONS.

LONDON:
JOHN WEALE, 59, HIGH HOLBORN.
1856.

LONDON
BRADBURY AND EVANS, PRINTERS, WHITEFRIARS.

RUDIMENTARY TREATISE ON GALVANISM

AND

THE GENERAL PRINCIPLES

OF

ANIMAL AND VOLTAIC ELECTRICITY.

TO HIS EXCELLENCY

COL. SIR WILLIAM REID, R.E., K.C.B.,

GOVERNOR OF MALTA.

MY DEAR SIR WILLIAM:

I have much pleasure in dedicating to you this Elementary Treatise on Voltaic Electricity; knowing the interest you take in the series of Rudimentary Works of which it forms a portion. It is by the wide spread of useful knowledge, through the aid of such publications, that we may hope to promote the advancement of civilisation, by ameliorating the generally uncultivated condition of the human race.

It would have been satisfactory to me if my Work had been more worthy of the honour of such a dedication; still I trust you will be so good as to accept this small tribute of my respect and regard, as expressive of my high appreciation of your exertions in the cause of Education and Science.

I remain,

My dear Sir William,

Yours very faithfully and truly,

W. SNOW HARRIS.

PREFACE.

THE wonderful agency commonly designated by the somewhat mysterious term, "Galvanism," has for a long series of years continued to awaken a popular and intense interest in almost every country. Its phenomena, bordering to a certain extent on the marvellous, and having an apparent and intimate connection with the vital principle, has necessarily given it additional and very popular claims to general consideration. It is, however, in modern times only that this agency, under the form of Voltaic Electricity, has received a real value, and has become of practical importance. Galvanism, considered as an occult and obscure section of Physics, has gradually resolved itself into a branch of Electricity; all its effects on the animal frame have been shown to depend on electrical powers obedient to certain laws, and so far reducible to the conditions of a science. To arrange, classify, and pursue systematically the march of this interesting department of knowledge, is the object of

this Rudimentary Work. Being an Elementary Treatise, intended for the use of Students, it is necessarily simple in its scientific character, and must consequently be expected to contain much with which the scientific world is already familiar. The Author, however, is still disposed to believe, that, whilst carrying out the great purpose of these Rudimentary Treatises, viz., the diffusion of useful elementary learning, he has not altogether failed in treating the subject under an original form, or in the production of many new facts not before made public.

It has been the Author's desire, so to treat and combine the various interesting questions which have arisen under the respective denominations of "Galvanism," "Animal," and "Voltaic Electricity," as not only to be of advantage to the student, but also to some extent useful to those advanced in a knowledge of general Physics, and so far to render the work not altogether unworthy of the attention of the scientific world generally.

CONTENTS.



CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CHEMICAL EFFECTS OF THE PILE.

CHAPTER VI.

HEATING EFFECTS OF THE PILE.

CHAPTER VII.

CURRENT MAGNETIC FORCE.

CHAPTER VIII.

RUDIMENTARY GALVANISM.

ANIMAL AND VOLTAIC ELECTRICITY.

CHAPTER I.

Electrical Fish—First views of Animal Electricity—Discovery and theory of Galvani—Investigations and theory of Volta—The Voltaic circle and Electro-motion—Electricity of contact—Electro-motive force and direction in the Voltaic circle—Various Electro-motive combinations of dry and moist Conductors—Current force.

1. The faculty possessed by a certain species of ray, a flat fish, found on the shores of the Mediterranean, of communicating a numbing sensation when handled by the fisherman, or even at a distance, through the medium of their nets, has been circumstantially recorded by the Greek and Roman philosophers in the early periods of the history of science. This fish was called by the Greeks "Ναρκη," from Ναρκαω, to "stupify;" it was termed by the Latins "Torpedo," from the verb "torpeo," to benumb: the phenomena were supposed to arise out of certain frigorific particles evolved by the fish.* It was not, however, until

* Aristotle says, "The torpedo conceals itself in sand and mud, and when fish approach which it would make its prey, it first benumbs them, and then devours them." He further adds, that "it does not confine this infliction to its prey, but it is enabled to benumb even men." Plutarch also remarks that the power of the torpedo not only stiffens those who touch it, but it even inflicts numbness on the hands of the captors through their nets.

electricity had made some progress as a department of science, that this wonderful physiological phenomenon began to be at all understood We owe to the labours of Walsh, a British philosopher, who undertook the investigation of this subject in the year 1772, the first demonstration, by physical experiment, that the numbing sensation communicated by the torpedo is no other than a modification of the ordinary electrical shock, as previously conjectured by Dr. Bancroft.* Walsh's experiments made at the Ile of Ré, at La Rochelle in France, in July, 1772, will be found in the 63rd vol. of the Phil. Transactions of the Royal Society. He there shows, that not only the shock, but the numbing sensation which the animal sometimes dispenses, expressed in French by the words "*engourdissement*," and "*fourmillement*," may be exactly imitated with the Leyden phial, by means of Lane's electrometer: † the regulating rod of which, to produce the latter effect, must be brought almost into contact with the prime conductor which joins the phial. He further refers this singular power of the torpedo to a double set of organs, under the control of the animal, and shows that its upper and lower surfaces, viz., the back and breast, are in opposite states of electricity: when a conducting communication is established between these surfaces through the human body, a shock is felt similar to that of the Leyden jar. This shock is transmitted freely by conductors, and impeded by non-conductors of electricity. Cavendish, in 1775,‡ and Dr. Davy, at a more recent period, 1832, § have both confirmed Walsh's

Plato, Pliny, Cicero, and other eminent philosophers of past times, all make mention of this curious fish. Alexander of Aphrodisias, Oppianus, and other of the more recent Greek writers of the second century, speak of the torpedo, and say that "it benumbs or shocks the body through a line or rod." Theophrastus states that the torpedo "can send its shock through harpoons so as to produce torpor in those who have them in their hands."

* Nat. Hist. of Guiana, p. 194.

† Rudiment. Elect., p. 103.

‡ Phil. Trans. for 1776.

§ Phil. Trans. 1832, p. 274.

experiments, whilst Matteucci in our own time has obtained sparks from it; no doubt therefore remains of the electrical numbing property of this species of ray.

2. Beside the torpedo, we find some other kinds of fish possessing a similar power. Amongst these, we have to notice more especially a peculiar species of fresh-water eel, found in the rivers of Surinam and Bengal, and termed the electrical eel, or gymnotus electricus. A specimen of this eel, more than three feet in length, was carefully preserved, between the years 1838 and 1842, in the apartments of the Adelaide Gallery, in London. Faraday, who subjected this wonderful fish to experiment, observed, that at the instant at which it exerted its force, all the water and conducting matter surrounding the fish became filled with electricity, so that almost any number of persons dipping their hands in the water of the tub in which the eel swam, received at the same moment a severe shock.*

3. The extraordinary faculty of these electrical fish, and which they exercise as an act of volition, cannot but be considered as one of the most engaging phenomena in electricity and physiology; we here behold nervous power transformed, as it were, into electrical force, so far pointing to the conclusion that all animals are more or less endowed with a species of nervous agency intimately associated with electrical action,—perhaps with vitality itself. The surprising discovery of the German and Dutch philosophers in 1746,† by which we are enabled to subject the animal frame to a peculiar and numbing shock, is apparently another and very important link in the chain of facts associating these two principles, and tending to connect still more intimately electrical agency with animal life.

4. About the year 1789, not quite one half a century after the brilliant discovery of the Leyden jar, Aloysii Galvani, a professor of Anatomy at Bologna, surprised the philo-

* Exp. Researches (1784). † Rudiment. Elect., p. 73. (59.)

sophical world by a further and most important advance in this department of physics. The attention of this celebrated anatomist was called to the fact, that the muscles and limbs of a frog recently dissected, became spasmodic and convulsed when exposed, under certain conditions, to the influence of sparks drawn from an electrical machine. As is not unfrequently the case, this phenomenon, so stupendous in its influence, in other hands, upon the future interests of mankind, was really accidentally observed; so true it is, that in cultivating the field of science, what we find is often more valuable than that which we seek. One of the professor's assistants happened, as it appears, to touch with the point of a scalpel the crural nerve of a frog recently dissected, just at the moment of the excitation of an electrical machine, preparing in the same apartment for experiment: immediately the whole limb of the animal became convulsed. Madame Galvani, an intelligent lady, being present, and for whose medical diet, it is said, the frogs were intended, directed her attention to the circumstance, and further observed that the convulsive movements invariably occurred at the instant sparks were being drawn from the conductor of the machine; of this fact she ran to inform her husband, who speedily convinced himself of the accuracy of her observation; and immediately commenced a laborious examination of the causes of the phenomenon. After repeating and varying the experiment in a most elaborate way, he announced to the scientific world, his conviction of the discovery of an "animal electricity," properly so called—or, in other words, that all animals are endowed with an inherent constitutional electricity; secreted by the brain and distributed through the nervous system, the principal reservoirs being the muscles, and each muscular fibre a sort of Leyden jar.* Although this

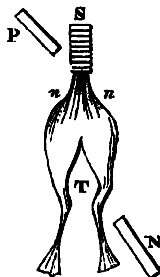
* De viribus electricitatis in motu musculari commentarius. Bologna, 1791.

extraordinary announcement was clearly a piece of pure, unsubstantiated hypothesis, yet was it received with enthusiasm throughout Italy.

5. The following are some of the leading and elementary experiments upon which Galvani based his very plausible and engaging theory—a theory which fascinated and led away captive the Italian physiologists of the day, and brought the dictates of the mind and the power of thought under the dominion of an electrical vitality, operating upon the whole animal economy by means of the organs of the brain, and the nervous system generally; here then was the real "nervous fluid," to which hitherto they had ascribed the phenomena of animal life.

Exp. 1. In the annexed fig. 1, we have a diagram of the dissected frog, as prepared by Galvani. The head and upper extremities are cut away, and the skin removed from the lower extremities; S is a remaining portion of the vertebræ of the spine; *n n*, the exposed nerves by which it is attached to the thighs and legs; P is a conductor either connected with or near the spinal nerves *n n*; and N another conductor, either connected with or near the muscles T.

Fig. 1.



Spasmodic contractions take place in the muscles of the lower extremities, T, and lively movements in the legs, whenever sparks from the electrical machine pass between the conductors P N, and intermediate muscular parts of the frog.

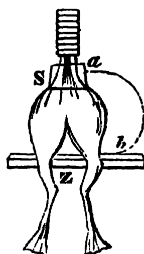
Similar spasmodic movements and convulsions ensue on drawing sparks from the conductor of the machine, at a distance from the conductors P N.

Galvani called the conductor P, in communication with the nerves *n n*, or near them, the nerve conductor, and the conductor N, the muscular conductor. It was found

desirable to connect the muscular conductor N with the earth; it is under these circumstances that the legs T evince the most lively motions.

Exp. 2. Instead of merely touching or directing the conductors P N towards the exposed nerves and muscles, let the nerves be coated with a metal, or placed in complete contact with it, and another coating or contact of a different metal be given to the muscles: convulsive movements occur whenever the two metallic coatings are joined by a third metallic substance, without any aid from artificial electricity, as in the last experiment. Let for example, S *a*, fig. 2, be the exposed nerves, leading to the lower extremity, and which have been enveloped in a leaf of silver, S *a*. Let the muscles of the thighs repose on a plate of zinc, *z*; when a metallic wire *a b* is made to join the silver and zinc, all the lower extremities of the frog become convulsed. To use Galvani's own description: "If," says he, "you lay bare the sciatic nerve of a frog, remove the integument, and place the nerve on a piece of zinc; and if further you place a muscle on a piece of gold, and then connect these different metals by any conducting substance, contractions are immediately produced. If, however, non-conductors are used to connect the metals, contractions are not excited."

Fig. 2.



6. Galvani was led to this new discovery by the mere accident of suspending his prepared frogs from the iron balcony of his terrace, by means of a metallic hook passed through parts of the dorsal column. He found convulsive contractions in the limbs, whenever the muscles came in contact with the iron, or the feet touched the balcony. His explanation of this phenomenon was, that the animal electricity of the frog is decomposed at the junction of the nerves and muscles, that the positive electricity goes to the nerves, and the negative electricity to the muscles; that in

fact there is virtually electrical discharge, similar in kind but differing in degree, to that of the electrical jar, the nerve and muscle being representative of the metallic coating on the glass.

Exp. 3. The nerves being cut off close to the spine, they are gently raised up on a thread of glass, and let down on one of the exposed muscles of the thigh. By this contact the limb becomes convulsed. In this experiment, we perceive muscular contractions arise, similar to those described *Exp.* 1, without the aid either of artificial electricity or simple metallic combination, but by the mere contact of different parts of the same animal; a result which went still further to confirm Galvani's hypothesis of a true animal electricity. This supposed animal electricity, Galvani further traced to all cold-blooded animals, and finally to warm-blooded animals; and he endeavoured to show that continual streams of electricity flow from one part of a living organised being to another, so long as a remnant of vitality remains. Cold-blooded animals, such as frogs and fish, retain the power of convulsive movement after death longer than others.

Such are the leading elementary experiments upon which the very engaging doctrine of animal electricity is founded, as taught by Galvani; and although the attention of this distinguished anatomist and philosopher had been so little directed to the operations of electrical power, as to lead him to pass by the true source of the results to be obtained, still we cannot but admire the singular and unwearied ability with which he pursued his repeated inquiries, and his extraordinary faculty of perception in treating the several phenomena as they sprang up from time to time under his hands.

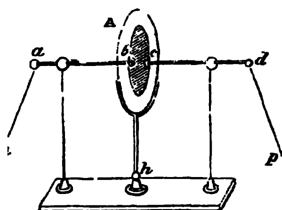
7. Galvani's theory of "animal electricity," and to which he always adhered, although, as already observed, at first received with much enthusiasm, did not continue to carry conviction to the minds of many eminent philosophers,

more intimately acquainted with the nature of electrical action. Amongst these was the celebrated Volta, Professor of natural philosophy at Pavia, who carefully investigated Galvani's recent discoveries; and notwithstanding that at first he was disposed to adopt Galvani's views, he found himself obliged eventually to abandon them as being untenable upon the principles of sound inductive science. Volta may be considered as the giant corrector and investigator of all Galvani had accomplished, and as having given, by his magnificent inventive power and independence of philosophical thought, an impetus to this branch of physics, such as must ever immortalise his name. His electro-motive pile, as he himself considered it (27), is a piece of electrical apparatus, from which all the great discoveries of modern times have emanated, and with which the scientific world is now so familiar. But for this apparatus, we might still have remained in ignorance of the chemical constitution of the alkalis and numerous other substances, those most astonishing transmissions of thought by telegraphic wires would probably have never arisen, nor should we have been in a position to estimate with any degree of probability the intimate relation subsisting between the agencies of electricity and magnetism.

8. On repeating the galvanic experiments just described, Volta is led to remark, that had Galvani been aware of the power of electrical sparks to excite muscular contractions, he would not have been so greatly astonished at the phenomenon he first observed (4). The dissected frog was really under the influence of electricity, induced in the surrounding matter by the operation of the electrical machine. To comprehend this fully, the student has only to refer to our Rudimentary Electricity (20), where the nature of what has been termed "electrical induction" is fully explained. It may, however, still be desirable to illustrate the nature of the inductive action operative in this particular case. The annexed fig. 3 represents an electrical arrangement calculated to detect the

inductive action of free electricity operating at a distance. Let A represent about five square inches of coated glass,* mounted on an insulator, *h*, and placed between two horizontal wires, *a b*, *c d*, also insulated, and terminating in minute brass balls, two of which, *b c*, are brought very near the coating on opposite sides of the glass; *n a* and *p d* are conducting wires, connecting the horizontal wires with the floor, or table, or the wall, in some point of a room distant from an electrical machine in action. When powerful sparks are taken from the conductor of the machine, minute streams of electricity will appear to pass between the balls, *c b*, and the near coating of the glass, so that after a short time the coated glass will have received a weak charge. If we now turn the glass aside, by means of a hinge joint at *h*, we may examine the electricity of the coatings by an ordinary electrometer, and thus detect the electrical state of the apartment in the point of the room in which the apparatus has been placed.† Now, the glass A is placed precisely under the same conditions as those of the frog in Galvani's laboratory; and since the frog is highly sensitive of electrical irritation, we here see demonstratively the immediate source of the muscular contractions. It was not, therefore, so immediately from the first observation and experiment of Galvani (4) that our present extended knowledge of the laws and operation of electricity as a great natural agency has been derived; it is rather to his second experiment (5),

Fig. 3.



* Coated glass. See Rud. Elect. (64).

† We are indebted to Mr. J. N. Hearder, of Plymouth, Lecturer on Natural Philosophy, for this ingenious experiment. He employs generally a small Leyden jar, well insulated, or an electrometer and condenser. The plates of the latter are a substitute for the coated glass.

in which he obtained muscular contractions by metallic contact, without the aid of common electricity, that we owe the astonishing results of modern researches in this branch of science. In fact, the passage of a very small quantity of ordinary electricity through the nerves of any animal is generally productive of tremulous muscular motion and spasmodic contractions, and this occurs not only in living animals, but in animals recently killed. Cold-blooded animals, such as frogs and fish, are the most sensitive of electrical irritation, and they retain this sensitive property a long time after death. The lizard, also, is especially sensible of weak electrical action.

9. On repeating Galvani's experiment, Volta first endeavoured to ascertain what was the least electrical force of which the frog was sensible, either in perfect life, or as prepared by Galvani after recent death, and he found it convulsed by the action of a small electrical jar so weakly charged as not to affect a delicate straw electrometer. Convulsions were obtained in a dissected frog by a jar, the charge of which did not affect his condenser.* So that in the frog, as prepared by Galvani (5), we have an electroscope of most extraordinary susceptibility. A further critical examination of Galvani's second experiment (5) shows that the contractions in the muscular fibre depend on a feeble action derived from the metals with which the nerves and muscles are brought into contact; a discovery which led to a new law of electricity, altogether independent of Galvani's animal electricity, and which Volta thus briefly stated.

10. The contact of different conducting substances, especially of metals, disturbs the existing state or distribution of the electricity found in the constitution of every kind of substance, and gives it a sort of impulse or tendency to move in a certain direction. This impulse is different in the contact of different bodies. Take, for example, three conducting

* "Condenser," Rud. Elect. (42).

substances, A B C. The impulsive power is different in amount when conductor A is brought to touch conductor B, than when placed in contact with conductor C. It is to be here remarked that the development of electricity by the contact of different metals, had been already announced by Bennett, who termed it "adhesive electricity," and supposed it to reside in all conducting substances.* The theory of a flow of electricity by contact, however, is due to Volta.

Now it is this spontaneous electricity, arising from the disturbed electrical state of the metals by their contact, which causes, according to Volta, the muscular convulsions of the dissected frog, as observed in Galvani's second experiment (5). Galvani's third experiment (6) may be shown to depend on a similar cause, substituting moist for dry metallic conductors. The following experiments are sufficiently illustrative of this sort of electrical action.

Exp. 4. A small leaf of tin is fixed by paste to the back of a living frog, and a piece of silver plate is applied under the thighs, so as to admit of gliding the plate along the animal, under gentle pressure, until it comes in contact with the leaf of tin on the back. Directly the silver touches the tin the frog becomes convulsed, and spasmodic contractions of the muscles instantly arise.

Exp. 5. The ischiatic nerve of a dog or lamb being exposed just below its insertion in the thigh, convulsive motions arise on placing two pieces of metal on the nerve, at a short distance from each other, and then uniting them in conducting contact through the medium of a metallic wire or arc, as represented in fig. 2.

11. Volta repeated and varied this kind of experiment in different ways, and extended it to lizards, salamanders, serpents, turtles, various kinds of fish, quadrupeds, and birds, and always with the same result. Not only were the results

* New Experiments on Electricity, by the Rev. A. Bennet, F.R.S.: J. Drewry, Derby, 1789.

certain in operating upon entire animals, but also upon portions of animals. In some cases, a grain of gold was sufficient to elicit electrical impulse through the nerve. He did not succeed with snails, slugs, oysters, and certain species of caterpillars, but he obtained muscular contractions in beetles, grasshoppers, butterflies, and common flies; also in lobsters.

An electrical discharge from nerve to muscle, or muscle to nerve, is not at all essential to the success of the experiment; hence the analogy of Galvani between the nerve and muscle, and the coatings of the electrical jar (4), is untenable. It further appeared that the muscles of animals under the control of the will were those principally affected by this species of metallic electricity. Muscles, such as the heart, not under the control of the animal, were found very slow, if not altogether insensible, to the electrical disturbance. In any case it is not by irritating the muscle, but by stimulating the neves, that spasmodic contractions are produced.*

12. The substances we term conductors of electricity, and by the aid of which spasmodic and convulsive motions are thus excited in living animal bodies, have been divided into two classes, distinguished principally by the terms Dry and Moist. *Dry conductors* are: all the metals, charcoal, pyrites, and other minerals; *Moist conductors* are: water, vegetable, and mineral acids, saline and other fluids. Simple contact between combinations of conductors of each class gives rise to what has been called electro-motive force, produced by disturbing and impelling in a given direction the natural electricity which the substances are supposed to contain. The most simple and effective arrangement is a triangular series of three conductors, differing in kind and degree of power. We either put a dry conductor between two moist conductors, or

* Galvani himself appears to have entertained at first some idea of a metallic electricity. He was certainly not altogether ignorant of it, as appears by the following notice, written in his own hand on the cover of a manuscript journal, date 1786: "Experimenta circa l'Electricité di Metalla."

a moist conductor between two dry conductors, the two moist or dry conductors being different substances, or otherwise three moist conductors differing essentially in kind are associated. We have in either case, according to Volta, a sort of electro-motive circulation through the system, by an impulsion either to the right or to the left, according to the nature of the combination and the particular substances in contact. The following diagrams are intended to designate these elementary combinations, the dry conductors being represented by a lozenge-shaped figure, the moist conductors by a curvilinear figure.

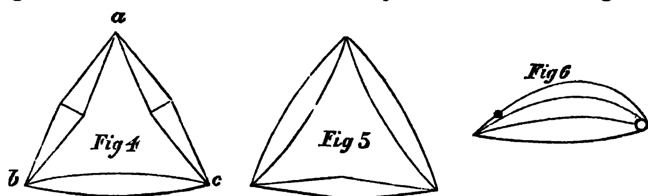


Fig. 4, for example, designates a voltaic combination of two first-class and one second class conductor. In fig. 5 we have a combination of two second-class conductors with one first-class. Fig. 6 represents a combination of three moist conductors only. The first arrangement (fig. 4) is the most powerful, the last (fig. 6) the least powerful. In either case we obtain, on Volta's hypothesis, a sort of electrical circulation. The series has been hence considered as circular, and the arrangement has been hence termed a voltaic circle, sometimes a galvanic circle.

13. We may in these combinations either consider the contact of the two first class conductors (fig. 4) as the source of the electro-motion, or otherwise the contact of the first and second-class conductors (fig. 4 and 5) as the source of it; or, we may refer the electro-motion to the contact of three conductors of the second class, differing essentially in kind, as in fig. 6. In referring the electro-motion to the contact of conductors of the first and second-class in the

combination (fig. 4), we have two actions to consider—for example, at points *b* and *c*; whereas in referring the result to the simple contact of the metals at point *a*, we have only one action to consider. Volta was led finally to adopt this latter view, and to consider the contact with the first and second-class conductors at points *b* and *c* as of secondary moment, and as merely serving to transmit the disturbed electricity of the metals. The combinations represented (figs. 5 and 6), however, in which electro-motion ensues without the presence of two metals, or without any metallic agency, throws serious difficulty in the way of Volta's conclusion. It is easy to see that fig. 5 is really the converse of fig. 4, and that any hypothesis we invent must necessarily comprise both cases. Volta was obliged, therefore, to adopt eventually a more liberal generalisation, and to admit that electro-motion is excited by the mutual contact of conductors generally, whether fluid or solid.* So that Volta's hypothesis, as thus modified, is this —the contact of conductors generally is a source of electrical disturbance, but the disturbance is more especially the result of the contact of metallic bodies. In some very valuable and recent modern experiments by Karsten, the electro-motive power of the voltaic circle is traced to the contact of the dry and moist conductors. A metallic substance, for example, when immersed in a liquid, becomes positively electrified. If it be partially immersed, the parts acquire opposite electrical states. Peclet also has shown that electro-motion may ensue either from the contact of two metals, or from the contact of metals with liquids, or from the contact of liquids only. Finally, it may arise by the operation of these three causes united.†

14. Admitting these views of voltaic action, it becomes requisite to verify by experiment the great general principle upon which Volta bases his hypothesis, viz., the development of electricity by the mere contact of metals; and to further

* Phil. Trans. for 1800.

† Becquerel, Traité de l'Electricité, and Archives of Electricity, t. i.

ascertain in what direction the impulse becomes directed, so as to determine the precise course of the circulation in the combinations indicated in figs. 4, 5, and 6. With this view Volta resorted to the following course of experiment—

Exp. 6. Procure two flat clean circular discs of different metals, silver and zinc, or copper and zinc, about 8 or 10 inches diameter. Insulate each on a slender and well-varnished rod of glass, as represented in the annexed fig. 7. Apply their flat surfaces to each other with very gentle pressure, holding each plate by its insulating handle. Separate the two discs, after contact, by a dexterous, simultaneous, and parallel movement one from the other, and then apply either of them to an extremely delicate electroscope. Both will evince signs of free electricity. The single gold-leaf electroscope, fig. 8, is well adapted to this experimental purpose. One of the discs should be applied to the leaf through the plate *p*, the other to the fixed ball through *n*. Proceed now to test the quality of the electricity by means of the double leaf electroscope, fig. 9, slightly charged with vitreous electricity; it will be found that the silver or copper plate tends to decrease the divergence, and the zinc plate to increase the divergence of the leaves. The reverse of this occurs if the electrometer be weakly charged with resinous electricity. The conclusion, therefore, is, that the zinc has been positively electrified by the contact, and the copper negatively, so that some electricity must have flowed from the copper or silver plate upon the zinc plate.*

Fig. 7.

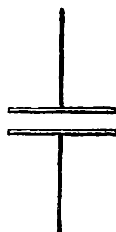


Fig. 8.

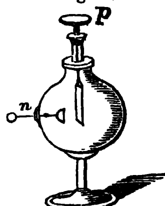
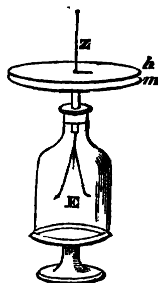


Fig. 9.



* For single and double electroscope see Rud. Elect., Chap. iii.

Volta conceives that the metallic discs employed in this experiment are not only motors of electricity, but that in bringing their extensive surfaces together, they further operate as condensers. He did not find it requisite to make a perfect contact in every part; provided the metals touched in a few points it was sufficient.

15. The preceding experiment requires extreme delicacy of manipulation; it is not always at the command of the student, beside that the electrical indication is very small. It is hence desirable to multiply the effect so far as possible by the aid of the condenser. The following is the experiment as carried out by Volta.

Exp. 7. In the preceding, fig. 9, E is a very delicate electroscope of divergence, *m* and *h* two light circular conducting discs, one *m*, placed on the cap of the electroscope, the other *h*, having an insulating handle *q*, is superposed upon this; the discs are preserved at a very small distance from each other by any intermediate non-conducting substance; such, for example, as a spot or two of sealing-wax on the lower plate.

The electroscope being thus arranged, we bring the metallic plates (fig. 7) into contact as before, and after separating them, touch the condensing plates *m h*, one with the zinc disc, the other with the copper, repeat this process ten or twelve times, then raise the plate *h* by its insulating handle *q*, and the electroscope E will diverge with positive or negative electricity, according to the particular metal disc applied to the plate *m*. Thus zinc will give positive, and copper negative, electricity. The single leaf electroscope just adverted to (fig. 8) may be employed with advantage in conjunction with condensers, one in communication with the plate *p*, another with the rod *n*. The electricity of the copper and zinc plates would be thus freely developed at the same time. In this way it may be shown, experimentally, that any two disimilar metals evince electrical signs after contact and separation.

The following are interesting modifications of Volta's original experiments just quoted, *Exp.* 6 and 7:—

Let the condensing and collecting plates *h m* (*Exp.* 7, fig. 9), be two zinc plates. Touch the lower plate *m* with a copper plate held in one hand, and the zinc plate *h* at the same time with a finger of the other hand; now proceed to raise the upper plate *h* by its insulating handle z, and the electroscope, if sufficiently delicate, will diverge with positive electricity.

Positive electricity, therefore, has flowed from the copper upon the zinc.

Let the condensing and collecting plates *m h* be now two copper plates. Touch the lower plate in this case with a zinc plate, and the upper plate with the finger as before; raise now the upper plate *h*, and the electroscope will diverge with negative electricity.

Negative electricity, therefore, may be said to have passed from the zinc upon the copper, or we may imagine that positive electricity has flowed from the copper as before.*

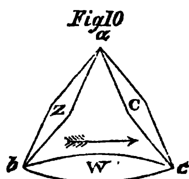
16. The order of the respective electro-motive energies of various metals amongst each other as determined by Volta is: silver, copper, iron, tin, lead, zinc; that is to say, silver would cause electricity to move toward copper, and the metals which follow it; copper, toward iron, and the following metals; iron toward tin, and so on. And since silver is found at one extreme of the series and zinc at the other, the most powerful impulse would be between silver and zinc, after this between copper and zinc. An extensive table of this kind may be formed including other metals—pyrites and charcoal—by which we arrive at still more powerful combinations. The following order or series has been deduced by Peclet, in which each metal is positive with respect to those which follow, being in reverse order to the preceding.

* For other forms of these experiments, see (55) chap. iii.

Zinc, lead, tin, bismuth, antimony, iron, copper, gold. In this series zinc takes electricity from lead, lead from tin, tin from bismuth, and so on.

17. The great theoretical assumption upon which all this rests, is, that the agency we term electricity is distributed in bodies throughout the material world in quantities proportionate to their attractions for it, called by Peltier inherent specific capacity; so that different substances are said to have different electrical capacities. Now, when two metals are brought into contact, their respective attractions for electricity are changed; one can contain more, the other not so much as in its previous state—hence a new distribution of the electricity natural to the two metals ensues. When we separate or withdraw the bodies from each other's influence, we restore the previous attractions of each, whilst the new distribution remains; consequently one will appear to be electrified positively or to be overcharged, the other negatively or to be undercharged.

This understood, let us now see, upon this hypothesis, what would be the direction in which the electricity would circulate in a combination of two first-class and one second-class conductor, as represented in fig. 4. In the annexed fig. 10, let z be a plate of zinc, and c a plate of copper, and let w be a fluid conductor in combination with these metals, the three bodies touching in points *a*, *b*, *c*. Then, since the zinc z takes electricity from the copper c (14), we obtain electro-motion in direction *a*, *b*, *c*; so that the circulation through the fluid, w, or second-class conductor, would be from the zinc toward the copper, and in the reverse direction above at the point of contact *a*. Volta did not find it requisite to bring the two first-class conductors into immediate contact at point *a*; it was sufficient if they touched through the medium of a metallic arc, as in *Exp.* 2 (5).



This source of electrical disturbance would necessarily determine the direction of the circulation without any reference to any minor action at the points *b* and *c*.

We determine the direction for the case of two conductors of the second class with one of the first, as represented in fig. 6, much in the same way; it being now admitted that these phenomena may result not only from the contact of metals solely, but from the contact of metals with liquids, or from the contact of liquids themselves; and this may be extended to fluids and even to gaseous substances.

18. We may readily conceive the second-class conductor W in the above fig. 10, to be the prepared frog of Galvani, and Z C the metals with which different portions of it were coated or placed in contact (5). Whilst in the arrangement with two second-class conductors (12) (fig. 5), we can understand the two second-class conductors to be different portions of the same frog joined by a metallic arc, or first-class conductor. In either case electro-motion through the animal ensues. The third weak combination (12) (fig. 6) may be taken to represent three different portions of a prepared frog; the leg, the muscles of the back or ischiatic nerves, and the blood or viscous fluids. Here then is Volta's reply to the objection that muscular contractions may be excited without the presence of metals; it is, therefore, an explanation of the experiments (6), *Exp.* 3. It is hence so far demonstrable that the muscular spasms observed by Galvani do not arise from a communication of animal electricity between different parts of the frog proper to the animal itself, but from electro-motion set up by the contact of the metals or other heterogeneous conductors employed in the experiments.

Volta's explanation of the phenomenon of spasmodic contractions by the contact of muscle and nerve of the frog, was simply this: that any two heterogeneous tissues, such as nerve and muscle, with an interposed moist conductor, constitute an electrical circuit; and that in the

case of contractions produced by the action of a single metal, he insisted on the fact, that slight differences in the condition of the metal itself were always present, and that these differences could always induce electro-motion. Thus he found, that when one extremity of a metallic rod was dipped in boiling water, the difference of temperature between that extremity and the opposite extremity of the rod was quite sufficient to cause the two ends to act as if consisting of different metals. Humboldt, in confirmation of this view, inferred that homogeneous metals might become heterogeneous as regards electro-motion, by the operation of slight changes in polish, density, and temperature of their different parts.

19. The following are practical illustrations of electro-motive force, by the combination of first and second-class conductors.

Exp. 8. Fill a tin or silver cup with plain water, and place the cup on a zinc plate, moisten the hands or fingers and place them, one in contact with the silver cup, the other with the zinc plate on which the cup rests; at the same moment touch the plain water in the cup with the tip of the tongue. A peculiar sensation and a saline taste will be immediately experienced, but which does not arise if we taste the water without contact with the metals. This then is a case of two metals and a moist conductor (fig. 4).

Exp. 9. Place a small piece of clean zinc between the upper lip and the gum, so as to sustain it there; place a small silver coin or plate on the tongue, and then let the zinc held under the upper lip descend so as to touch the silver; a flash of light will be often sensible to the organs of vision, and a peculiar acid taste will be experienced. This is again a combination such as represented (12) figs. 4 and 5. The experiment itself is by no means modern; Sultzer, in a work on Sensation, published in 1787, recites a similar experiment; the nature of the phenomenon, how-

ever, was not explained until Volta had discovered the electro-motive action of metals.

This operation of the voltaic circle on the nerves of taste may be further traced in the act of drinking fluids out of metallic vessels. It is a familiar observation, that porter drank out of a pewter or silver cup has a higher flavour than if taken from a cup of porcelain, which is really the fact. We have here a voltaic circle of the second class, represented (12) fig. 5; that is, a series of two moist conductors and one dry or metallic conductor. The two moist conductors are the porter and the saliva of the mouth, and the metallic conductor is the pewter or silver cup.

20. On a further experimental examination of the electromotive force of the voltaic circle, we find very considerable variation as to power in the combination of first-class conductors with second-class conductors differing in kind. The energy generally of such combinations is greater in proportion as the substances differ from each other. Thus, iron in contact, on one side with water, on the other side with nitrous acid, produces a powerful effect, especially in exciting muscular contractions. Silver, which generally has the least energy in common cases of combination with moist conductors, is found a very powerful electro-motor when placed between water and sulphuret of potassium. If an arc of metal touches the same fluid conductor at each end, then little or no electro-motion ensues. The second-class conductors must differ in kind.

Since then the power of the voltaic circle varies with the combination as to the kind and disposition of the substances employed, it becomes requisite to ascertain experimentally the particular combinations best suited to our purpose, so that the second-class conductors may be disposed according to their activity in a given arrangement.

21. Volta has distinguished second-class conductors by the terms—aqueous, spirituous, mucus, gelatinous, saponaceous, saccharine, saline, acid, alkaline, sulphurous, and suchlike.

Acids which are powerful exciters of electro-motion differ so considerably as to require careful classification from mineral to vegetable acids; the same may be said of saline fluids, according as they are solutions of neutral salts, earthy, or metallic salts. When we have determined in what order all these fluids must be arranged in regard to their application to metal A or metal B, we shall be then in a position to determine the most powerful combinations for the voltaic series.

The order of activity of certain fluids in combination with the greater number of metals, as determined by Volta, is as follows, beginning with the weakest:—1. Pure water; 2. Chalk and water; 3. Solution of sugar; 4. Alcohol; 5. Milk; 6. Mucilaginous fluids; 7. Animal gelatinous fluids; 8. Vegetable acids, including vinegar; 9. Solution of salt; 10. Concentrated mineral acids; 11. Strong alkaline leys and fluids; 12. Sulphuret of potassium, commonly called liver of sulphur. There are some slight exceptions in the combinations of sulphuret of potassium and also alkaline and saline fluids.

With respect to the order of the metals as regards these fluids, he found tin the most energetic, and silver the least, except for water or any aqueous conductor, or sulphuret of potassium; placed between these, silver exceeds all other metals. Of all the metals, zinc appears to be the most available as a positive metal; this metal, with gold or charcoal, or with silver, copper, or tin, in association with water acidulated by any mineral acid, yields energetic combinations. The action, however, depends much on the acid solution employed.

22. The following are two tables of electrical arrangements by Sir H. Davy; the first consisting of two first-class with one second-class conductor, the second of two second-class with one first-class.

TABLE I. (12), Fig. 4.

Voltaic combinations—Two First-class and one Second-class Conductor.

First Class—No. 1.	Second Class.	First Class—No. 2.
Zinc . . .	Solutions in water of :— Nitric acid. Muriatic acid.	Gold, Charcoal, Silver, Copper, Tin, Iron, Mercury.
Iron . . .	Sulphuric acid. Sal ammoniac.	Gold, Charcoal, Silver, Copper, Tin.
Tin . . .	Nitre. Neutral salts.	Gold, Silver, Charcoal.
Lead . . .	Oxygen. Atmospheric air, &c.	Gold, Silver.
Copper . . .	Solutions of Nitrate of silver, Mercury, Nitric acid, Acetic acid.	Gold, Silver.
Silver . . .	Nitric acid.	Gold.

TABLE II. (12), Fig. 5.

Voltaic combinations—Two Second-class with one First-class Conductor.

Second Class—No. 1.	First Class.	Second Class—No. 2.
Water: or solutions of alkaline, hydro-sulphurets, or solutions of Potass or Soda.	Charcoal. Copper. Silver.	Solutions of :— Nitrous acid. Chlorine. Muriatic acid.
Potass and Soda only active on the first three metals.	Lead. Tin. Iron. Zinc.	Any acid solutions acting on metals.

It is evident that in the wide range of metallic and liquid substances open to us, an almost infinite number of these electro-motive combinations are to be found, all of them

possessing specific peculiarities and degrees of force depending on the particular substances associated together, and on the circumstances under which they are placed. We may, for example, associate two metals with pure water only, or with concentrated or dilute acids or metallic salts, producing in each case different effects and degrees of power. The same may be inferred in the association of two moist with one metallic conductor. The most powerful combination as yet produced is an association of the metals zinc and platinum with nitro-sulphuric and dilute muriatic acids, discovered and applied by Grove.

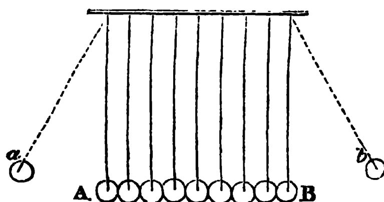
23. It may, perhaps, before concluding this chapter, be necessary to state more explicitly in what sense we employ the terms "electro-motion," "flow of electricity," "electrical current," and such like, more especially as the terms "current," "current electricity," are constantly reverted to in treatises on this branch of physics; indeed, much of the intelligibility of the subject depends on a good distinctive acceptation of verbal expressions.

It is always difficult, in dealing with such mysterious agencies as those of electricity and magnetism, to apply terms which shall not carry with them hypothetical notions of the forces themselves; the senses not having any cognizance whatever of occult powers in the way they have of ordinary things, we are led to look at the phenomena they present to us through the medium of analogies. It is in this way that, considering the source of electrical phenomena to be a peculiar species of invisible fluid, we imagine it to stream or flow through substances, or from one substance to another, and to constitute, whilst in motion, a current of electricity. The student must not, however, be tied by this figurative language, lest he limit the generality of his future researches; more especially, as the whole idea of a current is a pure assumption, it is quite possible, if not highly probable, that no such agency as an "electric fluid" exists. The term "current," however, is, in the present state of

these sciences, an extremely convenient term, and when cast adrift from the hypothetical idea of flowing matter, and employed, as expressed by Faraday, to designate progressive force of any kind, will be found a very legitimate and convenient form of expression.

24. Take, for example, the well-known mechanical experiment of a close series of suspended elastic balls, as represented in the annexed fig. 11. If one of the extreme balls, A, be raised as at *a*, and be allowed to fall with impulse on the series, then the opposite or extreme ball, B, will be struck off, and raised to a similar height, *b*, but all the intermediate balls will remain tranquil. Now, here is a good example of progressive force through the intermediate balls, which, without any great violence to our view of the fact, we may designate as a current of motion. Similarly, if a person applies his ear to one end of a beam of wood, or to a long metallic wire, whilst another strikes on the opposite extremity with a hammer, a sound reaches his ear, after a short interval of time, through the intermediate particles of the wood or metal; here we have again an instance of progressive force, viz., vibratory force, which we might designate as a current of vibration, or even a current of sound.

Fig. 11.



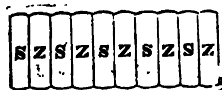
Now, in electrical force, such as we have been describing (10), we must treat the term "current" in all its generality and as really expressing "progression," unattached to any especial doctrine; that is to say, as simply designating progressive power, and which, as constituting a sort of axis of force, we come at last to consider as a cause of certain effects, such, for example, as those which, in the course of this work, it will be our endeavour to illustrate and explain.

CHAPTER II.

Attempts to unite the power of a succession of Voltaic circles—Discovery of the Pile or Voltaic series—"Couronne de tasses"—Positive and negative Poles explained—Discoveries of the British chemists—Terms employed by Faraday to designate the phenomena of the Pile—Summary of nomenclature—Contact and chemical theories of the Pile—Electrical column of Dr. Luc—Enumeration of the several effects of the Voltaic apparatus.

25. It is not difficult to perceive that the power of a simple Voltaic combination or circle of three substances is necessarily very limited; moreover, we see no means of multiplying the effect so long as the series is confined to one elementary combination. Volta sought, but at first without success, to extend the practical result of his theory, so as to obtain increased power; similar attempts were made by other philosophers. With the same view Professor Robison, seeing that the action of two single plates was very feeble, thought of uniting or concentrating the action of many pairs of plates by associating a series of circular zinc and silver discs of about an inch in diameter, one pair immediately following the other, as shown in the annexed fig. 12: but without any new result. Indeed it is clear that in such an arrangement each zinc plate is necessarily between two silver plates, and every silver plate between two zinc plates, all except the first and last.

Fig. 12.



The consequence of this is, that supposing Volta's theory to be at all correct, electricity will tend to move in opposite directions. If, for example, both surfaces of zinc are in contact with silver, electro-motion tends to arise from the silver upon the zinc (14), upon

both sides of it; hence, neither surface can possibly become electrically affected, the forces destroying each other. The same thing occurs, only conversely, with both surfaces of the silver in contact with the zinc, so that, however numerous the series, it is the terminating discs only which evince electrical disturbance, and we have still not exceeded the power of a single pair. Volta was not long in perceiving this, and his wonderfully inventive and perceptive powers enabled him speedily to triumph over the difficulty, and thereby to achieve one of the greatest conquests in physics.

26. We have seen (13), that Volta in applying his theoretical views to the case of contact between first and second-class conductors, fig. 4, was led to consider the electro-motive force of the contact with the second-class conductor as being extremely small, when compared with the energy of the contact of the metals—he so far considered the office of the second-class conductor as a mere means of promoting the circulation of the disturbed electricity, and as being a conductor without disturbing electro-motive force, a property which no first-class conductor has. In all solid conducting bodies, more especially metals, electro-motive force and conducting power are inseparable.

However questionable the accuracy of this hypothesis, it served the author materially in this case, inasmuch as it led him to interpose a second-class conductor between each pair of metals (25, fig. 12), which upon the faith of his hypothesis he imagined would not only serve to keep the counteracting surfaces out of contact, but would also carry on the continually accumulating electricity of the several metallic pairs, without exerting any disturbing or counteracting electro-motive power, so that the sum of the series would be eventually obtained. The result was triumphantly successful: the terminating plates of the series exhibited a high state of what has been termed electrical tension, and evolved a peculiar, yet painful shock, when touched with a moistened finger of each hand, very similar to the shock of the

torpedo and gymnotus already described (1) (2), and which, as in the case of the electrical powers of these curious fish, became perpetually renewed within itself by the continued operation of the elements of the series; here then was a crowning evidence of the truth of Volta's views of the source of the spasmodic muscular convulsions observed by Galvani (4), and which went far to invalidate altogether the hypothesis of an animal electricity as advanced by this distinguished anatomist.

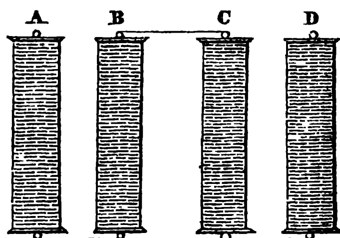
27. The form under which Volta first arranged his series of metallic and moist conductors was that of a pile; he placed, for example, one pair of metals upon another, separating them by a piece of cloth or cardboard moistened with a saline fluid, or water, thereby producing one of the most wonderful electrical instruments ever contemplated—an instrument which in succeeding times was destined to become almost omnipotent as a physical agent, and exert in its practical operation a vast influence on the destinies of the human race.

Volta's pile, or electro-motive apparatus, as he terms it, and which has immortalised his name, is thus constructed:—We procure about 25 thin circular or square plates of zinc, and as many of copper, about two inches square, and a corresponding number of pieces of common cloth of somewhat less dimensions—the latter is to be moistened either with water, or better with salt water or any saline solution. The zinc plates being carefully cleaned, we begin by placing a plate of either metal, say copper *c*, fig. 13, on a convenient insulating base, and upon this, a plate of zinc *z*. Then we superpose upon this a disc of moist cloth *m*; this completes a first combination. We now commence again with another plate of copper, piled over the cloth, then a plate of zinc, then another piece of moist cloth, and so on in series, until we arrive at a terminating

Fig. 13.

plate of zinc, *z*. The result is a self-acting electrical machine, powerful in proportion to the extent and number of the series. If the series be extensive it is requisite to build up the pile between supports of glass rods, or baked wood varnished, and if prolonged beyond the limit of such supports, then to build up a second column, and unite the opposite terminations of the two by a metallic arc, as shown in fig. 14. If pile A terminates below in copper, the added pile B must be united at its zinc end, C above at its copper end, D below, at its zinc end, and so on.

Fig. 14.



28. According to Volta, electricity moves from first copper plate *c* fig. 13 upon the superposed zinc *z* (15). The moistened cloth now operates in transmitting by conduction the disturbed electricity to the next plate of copper above; this plate of copper acquires the same charge as the zinc beneath, and is now in a state to act further on the zinc above and the copper plate below it, so that it now parts with still more of its electricity. In this way, every new plate, or pair of plates, continues to receive and exhaust the electricity of those beneath them. The quantity in the last plate of zinc, therefore, will increase in an arithmetical progression as we build up the pile, and the quantity in the copper at the base will decrease, leaving the two terminal plates in extreme positive and negative states.

It is quite evident that upon Volta's hypothesis, an electro-motive pile of this kind with three first-class conductors is impossible, since no solid conductor has been yet found which is not at the same time electro-motive. If such a substance could be obtained we might then construct a pile with dry conductors alone.

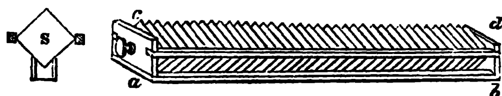
29. Volta considered his pile, in the way he constructed it, as closely resembling the electrical organ of the torpedo; he calls it "organe électrique artificiel." The points of resemblance are these: it is composed entirely of conductors, but of different kinds and power; it is active in itself, without the aid of a supply of artificial electricity; its operation is continuous, and it is capable of giving a succession of shocks without any apparent diminution of its power. With a series of twenty discs of about an inch in diameter, there is no difficulty in obtaining strong electrical indications. The electroscope and condenser become so powerfully affected as to emit a spark by a single contact, and with a pile of 40 pieces a shock is obtained, powerfully affecting the hands and arms, one hand touching the zinc and the other the copper extremity of the pile. A pile of 120 pieces, or 60 pairs of zinc and copper, about two inches in diameter, or two inches square, with intermediate cloth moistened with a saline fluid, such as a solution of common salt, constitutes a very efficient series: circular plates of zinc and common penny pieces may be used; zinc and silver is still more efficient.

30. The pile, although considered by its inventor as a perpetual electrical machine, is really not so for any length of time; its power declines as the intermediate moist conductor begins to dry, and changes take place in the fluid it contains, so that at length the surface of the plates of zinc, which is seldom pure, becomes covered with oxide. The perpendicular series tends also to press the fluid out of the wet cloth. We may avoid some of these defects by covering the zinc plates with mercury, which is best effected by moistening the surface with dilute sulphuric acid, and then rubbing a few globules of mercury over it. This is found to preserve the impure zinc from decay, so long as the extremities of the pile are out of metallic communication. The zinc of commerce is in fact very impure, and contains small portions of other metals, such as lead, copper, and iron; these metals, according to Faraday, are set free by the action

of the saline solution, and constitute with the zinc plate so many small voltaic circles, causing a rapid destruction of the metal. By covering the surface with mercury we bring it into a uniform condition, and so avoid the minor local action by which one part becomes a discharger to another.

The annexed figure (15), represents a horizontal series or

Fig. 15.



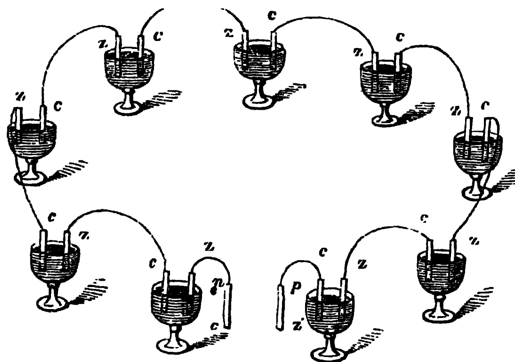
pile, as arranged by the author, having amalgamated zinc plates; it is very efficient and convenient. The plates are square, and are set lozenge fashion, the lower points resting between two strips of glass, fixed on a long board, *a b*, and are supported by side rails of baked wood varnished, as indicated in the section *s*; the side rails are secured to blocks, *c d*, at the extremities of the base, *a b*. Two screws, one at each end, pass through these terminating blocks, by which the series may be a little compressed; they serve also as the conducting terminations of the pile, and from these points, shocks and all the other electrical effects of the pile may be obtained. Two batteries of this kind, with 50 pairs of metal plates in each, constitute a powerful apparatus.

31. The voltaic pile, or series of electro-motive circles, was made to assume in the hands of Volta another and perhaps a still better form, termed by him "Couronne de tasses." In this arrangement, represented in the following fig. 16, alternating pairs of zinc and copper plates, z c, connected by metallic arcs, *z c*, are immersed in glass cups, containing a saline solution, and are arranged in the order of metal, fluid, metal, that is *c f z*, *c f z*, *c f z*; the last plates, c z, terminating in other plates, *p n*, which act as conductors to the series. The last plates, c z, evince opposite electrical states. The tension of the extreme plates, *p n*, is as the number of alternations or goblets, and consequently increases

in arithmetical progression. It is easy to see by a little reflection, that this arrangement is in effect the same thing as the pile (27), fig. 13, except that the plates of zinc and copper, instead of being in precise contact, are united electrically by the metallic arcs *c z* (17). Volta usually employed this form of his apparatus; his series consisted of about 50 cups filled with a warm saline fluid, the metals being zinc and silver. Having arranged the plates in the order of zinc, fluid, silver, he united the zinc of one cup with the silver of the next, thus forming a succession of electro-motive circles (17) in such a way as to obtain the sum of the whole.

32. The extremities, c, z, fig. 16, of the "Couronne de tasses," or of the pile (12), fig.13, concentrating, as they do,

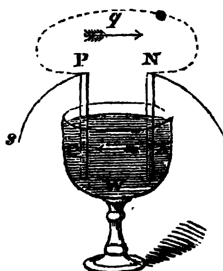
Fig. 16.



the united positive and negative forces of the series, have been termed its poles; the zinc extremity, z, being the positive metal, has been termed the positive pole; and the copper extremity c, being the negative metal, has been termed the negative pole. Some little confusion and misapprehension, however, has arisen relative to the real import of these terms, as applied to the terminating plates of the series; it will, therefore, be as well to elucidate this point by a brief analysis of a simple circle.

33. Let the annexed fig. 17 represent one of the elements of the "Couronne de tasses," (32) fig. 16, abstracted from the series: z being the zinc plate, and c the copper. The direction of the electro-motion in this series through the fluid w will be always from z towards c, as already explained (17), and if instead of connecting the metal arcs, P*s*, N*v*, with other zinc and copper plates, as represented in the last figure, we imagine them to constitute a single arc, uniting the respective plates z c, as indicated by the dotted line P *q* N, then the return circulation above would be in the direction P *q* N, that is to say, according to Volta's doctrine, electricity would flow above from the copper c towards the zinc z, at what may be considered the points of contact of the two metals (17), and from the zinc z towards the copper c, through the fluid below.

Fig. 17.



Now the pole *from* which electricity proceeds is to be termed the positive pole, and the pole *towards* which it flows and enters, the negative pole; so that, although the copper c be called the negative metal, it still constitutes the positive pole in this simple circle; and although zinc z be called the positive metal, it constitutes the negative pole. Further, it may be perceived that any metal made to terminate the arcs, N*v*, P*s*, beyond P, N, would have nothing to do with this arrangement, if kept out of liquid contact with other metals, such for example as the exterior plates *p*, *n*, in the preceding fig. 16. The student has only to remember the great cardinal point, that in the fluid medium *below*, electricity flows *from* the zinc upon the copper, and from copper to zinc, through the metallic arc above. If then we consider c z, fig. 16, as the terminating plates of the series, the last copper plate, c, will be the

positive end of the series, and the last zinc plate, z, will be the negative end, so that if the series terminate in a single zinc plate, *p*, on the one side, and in a single copper plate, *n* on the other, both external to the fluid, this zinc plate is so far the positive pole, and the copper the negative.

34. Reverting here to the case of the pile (27), fig. 13, it is easy to see that the last plates of copper and zinc, being out of a fluid contact, and beyond the real extremes of the pile, they have nothing to do with the electro-motive action; they are, in fact, merely substitutes for simple conductors transmitting the Voltaic power from the last plates in contact with the moist conductor. If, therefore, the first plate at the base of the pile in contact with the moistened cloth be a zinc plate, as in fig. 13, that will be the plate into which the circulating electricity of the pile would enter, supposing the extremities of the pile joined by a metallic arc, no matter for the first copper plate beneath it at the base of the pile. Similarly the last copper plate in contact with the moist conductor above would be the plate from which the circulating electricity would proceed, without regard to the terminating zinc plate above it at the summit of the pile; both the terminating plates, *z c*, fig. 13, might be therefore removed without any detriment to the course of the electro-motion. These plates become the positive and negative ends of the pile only in virtue of their transmitting the circulating electricity; they are, as it were, the doors by which the circulating electromotive power leaves and enters the pile as indicated in the terminating plates, *p*, *n*, fig. 16, outside the cups; hence it is, that whilst in a single pair of plates, or simple circle, represented in the last fig. 17, the copper is the positive pole and the zinc the negative, we find in a compound circle, such as the pile, or "Couronne de tasses," fig. 16, as *usually arranged*, that the zinc *extreme p* becomes the positive pole and the copper extreme *n* the negative. It would be, however, as observed by Priestley, of no sort of consequence in which of

the metals the series or pile terminated,—they might be both copper or both zinc—provided they were detached from a succeeding moist conductor in further communication with the series. It happens, however, in the pile (27) fig. 13, that the positive metal is at the positive extremity of the pile, and the negative metal at the negative extremity. We have, in illustrating and explaining these conditions, taken the copper as the first plate or base of the pile, in accordance with the supposition before given (27), fig. 13.

35. No sooner had Volta's paper "On the Electricity excited by the mere contact of conducting Substances," and in which he announces his discovery of the electro-motive apparatus, been read at the Royal Society, 26th June, 1800,* than the British chemists commenced a series of operations with it, and almost immediately detected its wonderful power as a chemical agent. Messrs. Nicholson and Carlisle were at first the most active, and they lost no time in constructing a pile of silver and zinc plates, with an intermediate moist medium. They at once confirmed all that Volta had advanced relative to its electrical properties, and found the zinc extremity of the series positive, and the silver extremity negative. Observing a minute stream of gas to arise from a globule of water resting on the upper plate of the pile, and in contact with a wire connecting the lower plate, they were led to investigate attentively the source of this action, and the nature of the gas evolved at the extremity of the wire; the gas appearing to be hydrogen, they proceeded to introduce two wires into a glass tube, filled with water: this they placed in the circuit between the extremes of the pile: immediately a stream of gas was observed to come out, as it were, of the wire connecting the negative pole, whilst the opposite wire became covered with oxide. On collecting the gas, they found it to be hydrogen; when two wires were employed, not easily oxidable (such, for example, as gold or platinum), then a stream of gas was observed to

* Letter to Sir Joseph Banks, P.R.S.

proceed from each wire: the gases, being separately collected, were found to be hydrogen on the one side, and oxygen on the other; which two gases, as shown by Cavendish in the "Phil. Trans." for 1784, were actually the constituents of water: the water, therefore, in the tube had been decomposed and separated by the agency of the pile into its constituent elements.

36. These beautiful and surprising experiments caused, as may be readily imagined, a deep sensation in the scientific world: Cruickshank, Wollaston, Davy, and other eminent chemists in this country, together with Fourcroy, Thenard, Ritter, and other great continental chemists, prosecuted them with intense ardour. Their progress became wonderfully facilitated by a new disposition of the pile, contrived by Cruickshank, who placed Volta's apparatus under the form of a trough, divided into cells by the series of pairs of metallic plates themselves, and into which was poured an acid solution.* By this contrivance, the activity, power, and convenience of Volta's pile became increased to an astonishing degree; so that, when several of these troughs, or batteries, were united, the most surprising results were obtained. Davy, through the agency of a similar, but a still further improved arrangement, detected the chemical constitution of the alkalies, and resolved potass and soda into metallic bases, united with oxygen. A series of new substances were speedily discovered, the existence of which had never before been imagined: oxygen, chlorine, acids, and many other substances, were all dragged, as it were, to the positive pole; whilst metals, inflammable bodies, alkalies, and earths, became determined to the negative pole of the battery (34.) When wires, connected with each extremity of the new battery, were tipped with prepared and well pointed charcoal, and the points brought very near each other, then a most intense and pure evolution of light followed; which, on separating the points, extended into a gorgeous arc.

* See Fig. 25 (59).

Metallic wires, joining the extremes of the series, were heated and fused: a thick wire of platinum, the most refractory of metals, soon became white hot, and glowed with a vivid incandescence.

37. Chemistry was thus put in possession of an agent far more searching and powerful than any it had as yet been enabled to command. The most stubborn substances were constrained to yield up their constituent elements to this omnipotent power. Inflammable elementary bodies, such as hydrogen,—also metallic bodies, earths, and alkalies,—were all constrained to travel, as it were, and appear at the negative pole of the battery (34), whilst oxygen, acids, and other bodies, became similarly commanded to appear at the positive pole (34.) In more recent times, this apparatus has been applied as a magnetic agent of almost unlimited means; and it is quite impossible to say in what new direction its powers may not become directed. Volta himself had certainly but a faint idea of the giant force he had thus called as it were into being, nor did he participate, in any remarkable degree, in the brilliant discoveries elicited by his apparatus directly it came into other hands, so rapid and immediate were the results; occupied as he appears to have been in the defence of his doctrine of electro-motion, and in its application to physiological inquiries, his attention was necessarily turned into other channels. In fact, partly from this cause, but in great measure from failing health, he did little in this branch of physics, so peculiarly his own, after his apparatus fell into the hands of the British chemists.

38. Faraday, in our own day, with his accustomed activity and wondrous powers of research, has contrived to throw a large beam of light on the nature and operation of the voltaic apparatus: he has classified, investigated, and arranged the phenomena of the pile in a way so orderly, so original, and so lucidly comprehensive, as to leave little further to be desired up to the present state of this branch of science. Amongst the profound and perspicuous views

of this celebrated philosopher, his proposed nomenclature of terms, applicable to the pile and its attendant phenomena, necessarily demands attention here, as being of paramount importance to a further elucidation of our subject.

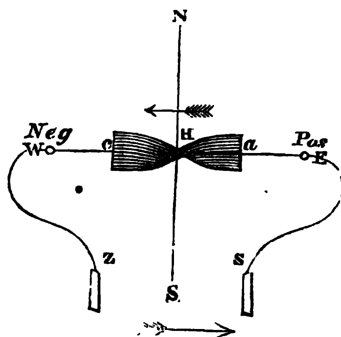
We have already seen (32), that, in the ordinary phraseology of the pile, we apply the term "pole" to each extremity, distinguishing the zinc and copper extremes by the terms "positive" and "negative." Thus the zinc extreme has been called the positive pole, and the copper extreme the negative pole. These terms have a certain accepted meaning, and Davy was led to infer, from the selection of substances, as it were, by these extremes (36), that there resided in them certain attractive powers.

Faraday, however, has shown, by a conclusive train of experiment, that this notion is untenable,—that the decomposing force is not at the poles, but within the substance itself, when acted on by the electrical current. He, therefore, considers what we term the poles of the series, as being merely the doors or ways by which the current enters a body and leaves it again. Such for example as the terminating plates *p*, *n* (32) fig. 16. When the poles are actually in contact with the body, as indicated in the following fig. 18, they limit its extent in the direction of the current. He is hence led to banish the term pole, and replace it by the term "electrode," from the Greek of ηλεκτρον, for electricity, and οδος, a way: this term he applies to any surface whatever, *p*, *n*, fig. 16, whether metal, water, or air, and which limits the extent of the body under decomposition, and the direction of the current as poles of the voltaic apparatus.

39. The actual surfaces of the body itself, through which the current enters or leaves the body, being important places of action, he is careful to distinguish these from the poles with which they are commonly in contact, and from the electrodes just mentioned, with which they are always in contact. With this view, he seeks a natural standard of direction, much in the same way as we sought in this

country an invariable standard of measure in the length of a pendulum, vibrating seconds in the latitude of London, or, as they sought in France, in the length of an arc of the meridian. Now the direction in which the sun apparently moves is a standard direction of this kind, being from east to west; and this direction being further inferred, from the laws of electro-magnetism, to be the direction of certain electrical currents circulating round the earth, at right angles to the position of the magnetic needle, we have thus arrived at an invariable standard of comparison. With an amount of precision and ingenuity peculiar to himself, and with a view of avoiding all illusory hypotheses, Faraday proposes to consider the substance acted on by the battery as being always in an east and west line; in which case, the current would have the natural standard direction just referred to. In the adjoining fig. 18, for example, let S N and E W be the cardinal points of the compass; in which E W is consequently an east and west line. Let H be a given substance, placed in the circuit *s* E *a* H *c* W *z*; that is, between the wires *s* E *a* and *z* W *c*, proceeding from the opposite extreme plates of the series, *z s*; the current passing through it in the direction E W. This understood, the surface *a* of the given body H on the east side, and into which the current is supposed first to enter, is termed "*anode*," and the surface *c*, on the west side, from which the current is again supposed to issue, is termed "cathode," from the Greek ανα and κατα, upwards and downwards, and οδος, a way; that is to say, the way in which the sun gets up, and the way in which the sun goes down. The *anode a*, fig. 18, is, therefore, that surface of the body H, under decom-

Fig. 18.



position, at which the current *enters*; it is its negative extremity (33), and is directly *against*, or *opposite*, the positive electrode, or door, on the side E: here, at this positive electrode, are evolved oxygen and all acids, iodine, chlorine, &c. &c. The cathode *c*, on the contrary, is that surface of the body H at which the current passes out or leaves it (30), and is directly against, or opposite, the negative door, or electrode, on the side W: here, at this negative electrode, appear hydrogen and other inflammable elements, metals, &c. &c. Imagine, for example, the substance represented by H, in fig. 18, to be immediately between the two extremes, *p*, *n*, of the "Couronne de tasses," (32) fig. 16. In this case, the plate *p* would be the positive *electrode*, and the surface *a* of the body H, in contact with it (fig. 18), would be the opposed *anode*. The electrode would be positive, the current passing out of it; the anode would be negative, the current passing into it. Similar reasoning applies to the opposite electrode *n*, fig. 16, the opposed surface *c n* would be the negative electrode, the current entering into it, and *c*, fig. 18, the cathode, which would be positive, the current flowing out of it.

Faraday has shown that the electrode, *p z*, *n c*, fig. 16, may be fluid, solid, or gaseous, that is, the substance acted on may be limited by water, or even air.

40. This understood, we have next to observe that any substance capable of being directly acted on and decomposed by the current—water, for example, whose constituent elements are two gases, oxygen and hydrogen, and which, under the influence of the current (35), at once separate and travel, one to the positive, the other to the negative electrode, or door-ways—is termed an "electrolyte," and when resolved into its constituent elements is said to be "electrolysed" (analogous with "analysed"), from the Greek ηλεκτρον, and λυω, to loosen: such a substance is further said to be "electrolysable."

Substances which do not *directly* yield up their elements in this way, but which only do so through the agency of some

secondary process, by which they decompose on reaching the electrodes, are not included in this class of bodies, and hence are not considered as being pure electrolytes.

41. Finally, we have an appropriate term to designate all those bodies which are thus unloosened, to travel or pass to one or the other of the two electrodes: these, as a whole, are called "ions," from the Greek ἰὼν, participle of the verb εἶμι, to go. Those ions which go to the anode *a*, fig. 18, and appear at the positive electrode, or pole *p*, fig. 16, are termed "*anions;*" those which go to the cathode *c*, fig. 18, and appear at the negative electrode *n*, fig. 16, are termed "*cations*," from the Greek neuter participles ανιον, or that which goes up, and κατιον, or that which goes down; still preserving the figurative idea of rising in the east and setting in the west, as in the line EW, fig. 18. Thus water is said to be an *electrolyte*; is *electrolysable*; when *electrolysed*, it evolves two *ions*, oxygen and hydrogen (33): oxygen is an *anion*, found at the positive electrode; and hydrogen is a *cation*, found at the negative electrode. Similarly, all bodies—as acids, chlorine, iodine, &c.—found at the positive electrode, or pole, are *anions* (37); whilst inflammable bodies, earths, and alkalies, found at the negative pole, are *cations*.* In the old phraseology, anions would have been called electro-positive bodies, and cations electro-negative bodies, being under the supposed influence of direct attractive forces, residing in the opposite poles of the battery; and, instead of being said to be electrolysed, they would have been considered as being "*electro-chemically*" *decomposed.*

42. Although a new and unstudied nomenclature may ill suit those whose views and habits have for a long period been trained in another sort of school, nevertheless, the terms just explained, and which have been so judiciously

* According to Professor Whewell, "cathions," would be more relative to "cathode" and would do less violence to the habits of English pronunciation, although the analogy with the Greek derivation requires "*cation.*"—Hist. Ind. Sciences, vol. vi. p. 185.

introduced by Faraday into this department of physics, will be found of immense advantage to its future progress, being definitely intelligible; carrying with them no illusory ideas, they express, in fact, the actually observed phenomena, and must be free from all confusion; and the student will do well to familiarise himself practically with the new nomenclature.

The following brief recapitulation of it will be found useful in the way of reference:—

TABLE III.—*Nomenclature.*

Terms.	Significations.
Electrode . .	Put for pole: the way or door by which a current enters or leaves a substance—it may be either positive or negative.
Anode . . .	That surface of a body receiving the current on the positive side of the series; the side on which the sun gets up, supposing the current to flow from east to west, is next the positive electrode.
Cathode . .	That surface of a body from which a current passes out towards the negative side of the series is next the negative electrode.
Electrolyte . .	Any substance whose constituent elements are directly separable by the influence of the voltaic current.
Electrolysis .	The result of a chemical decomposition analogous with "analysis."
Electrolysed . .	The actual separation of a substance into its constituents—stands for the old phrase, "electro-chemically decomposed."
Electrolysable .	Admitting of being chemically decomposed.
Ions . . .	The separated constituent elements of a substance.
Anions . . .	Ions or elements found at the positive electrode.
Cations . .	Ions or elements found at the negative electrode.

43. Volta's hypothesis of electro-motion, and his application of it in further explanation of the action of his pile,

although ever to be regarded as the conjecture of an original and sagacious mind, is nevertheless embarrassed by considerable difficulty, and is scarcely tenable as a general and fundamental principle adequate to a solution of the infinite variety of phenomena which have since presented themselves; it is now well known that the fluids of the pile by their action on the most oxidable of the two metals, is the great, if not the only course of the voltaic current. Another theory of the source of power in the voltaic pile, has hence arisen, termed the chemical theory, in contradistinction to the theory of Volta, which has been termed the contact theory. It will be requisite to briefly revert to the merits of these opposite theories, inasmuch as they have excited very extraordinary attention in the scientific world, and have been made subjects of profound philosophical controversy by all our eminent chemists.

Contact theory.—This theory, as we have already seen, (10), (13), (16), assumes that when different substances are brought into contact, there is a new distribution of the electricity inherent in the bodies, *e. g.* some portion of the electricity of the one flows towards, and is received by the other, and this effect is more especially evident in the metallic contact, (13). It further assumes that in the voltaic circle (17) although the touching bodies have respectively given and taken electricity, still they cannot support the charge; but discharge their opposite electricities one into the other through a third substance placed as it were behind them, and yet they remain still in opposite electrical states by a continual renewal of these states by the contact of the metals, and thus by discharging into particles of matter similar to themselves the contact is the source of an electrical current, that is progressive force (23), which current becomes, as expressed by Faraday, an axis of power when brought to operate on other substances.

44. The *chemical theory* of which hitherto we have said little, assumes: that in the voltaic pile the source of the

current, and consequently the source of its power, is to be sought for in what has been termed the chemical action of the pile, that is to say, the action set up between the elements of the fluids of the pile and the metals; in consequence of which electricity becomes evolved in large and overwhelming quantity, and circulates according to certain laws of force under the form of a current.

We are indebted to Fabroni for the first step towards a chemical theory of the pile, who observed that pure mercury preserved its lustre for a long time if kept out of contact with other metals; but in contact with zinc or other metals it oxidated rapidly. He observed the same fact in a variety of different metals, such as tin and its alloys, iron with copper, and he concluded that this reciprocal action was similar to other chemical combinations, and was the source of the electricity evolved by the pile. The results of his researches were communicated to the Florentine academy in 1792; from which he infers that all galvanic effects are no other than chemical operations. Priestley at an early period of Volta's discovery, remarked, as already stated (34) on the insufficiency of the prevailing theory in explanation of the phenomena of the pile; his view was, that the calcination, as he terms it, of the zinc, supplies "phlogiston," and when that ceases, the action of the pile is at an end. Wollaston, in a valuable communication to the Royal Society in 1801, clearly shows that the operation of the pile is invariably connected with oxidation and other chemical changes. If, says he, "a piece of zinc (meaning the zinc of commerce, not pure zinc) and a piece of silver have each one extremity immersed in the same vessel, containing sulphuric or muriatic acid, diluted with a large quantity of water, the zinc becomes dissolved, and yields hydrogen gas by decomposition of the water, but the silver not being acted on, has no power of decomposing the water. If we bring the silver and zinc, however, into contact, or there is any metallic communication made between them,

then hydrogen gas is formed also at the surface of the silver." Again he says, "We see in this experiment, that the zinc without contact of any other metal has the power of decomposing water; and we can have no reason to suppose that the subsequent contact of the silver produces any new power; the silver serves then merely as a conductor of electricity, and thereby occasions the formation of hydrogen gas." It is in fact, as he previously remarks, an established fact of the pile, that when water is placed in the circuit, if the power be sufficient to oxidate one of the wires, the other wire gives off hydrogen (39); since therefore the extrication of hydrogen in this case depends on electricity, it is highly probable that for the conversion of hydrogen into gas, electricity is also requisite in other instances. In the above example, for instance, electricity is evolved during the action of the acid solution on the zinc; the transition of this electricity between the fluid and the metal is the immediate source of the hydrogen gas.

45. Many conclusive experiments may be adduced to show that electricity is freely evolved during the chemical action of two substances on each other, producing new combinations.

Faraday has calculated that as much electricity is employed in holding together the two elementary gases, oxygen and hydrogen, in a grain of water, as is present in a discharge of lightning. A single grain of water acidulated so as to facilitate conduction, requires a current of voltaic electricity to be continued through it for nearly four minutes, in order to resolve it into its constituent elements, which current must be of sufficient force to retain a platinum wire of about the $\frac{1}{104}$th of an inch in thickness, red-hot in air during this time. Comparing such a discharge with that of the ordinary electrical battery, he finds that the quantity of electricity evolved in the decomposition of a single grain of water is equal to that of a "very powerful flash of lightning." *

* Exp. Researches, (853).

46. The fact of the evolution of electricity during chemical action being incontrovertible—let us now see how in the voltaic series a current becomes established in a given direction—the power of which is adequate to so many wonderful effects. Faraday treats this question with his ordinary clearness. We have to observe, first, that little or no chemical change occurs when pure zinc, or zinc amalgamated with mercury, is employed in the voltaic series so long as the circuit, C P *q* N Z, fig. 17, is incomplete; that is to say, so long as there is no metallic contact between the two metals. We have merely in this case a state of electrical tension between the fluid and the metal having the greatest affinity for its oxygen. The chemical affinity exerted between a particle of metal and a particle of oxygen, although not at the instant sufficiently powerful to admit of the metal seizing the oxygen and expelling the hydrogen, is yet sufficiently powerful to bring the particles into opposite electrical states of tension, or polar conditions of high intensity,* in which state they might continue without further change, did not some new condition arise to disturb it. Suppose then a plate of pure or amalgamated zinc to be thus circumstanced, and to be partially immersed in a dilute acid solution, then immediately the contact of the metal and the water is complete, and the metal becomes as it were wetted with the water, we have this electrical state of tension induced. Let us now suppose that a second metal be introduced into the fluid in a similar way, a plate of copper for example, not having the same affinity for the oxygen of the water, and that we proceed to complete a conducting metallic communication between these plates, or cause them in any way to touch each other through a metallic arc, as represented in fig. 17 (29), or otherwise directly, as in fig, 4 (11). Then this induced polar condi-

* "Electrical Polarity," see Rud. Electricity (98) p. 111. For "Tension" see (120) p. 141.

tion becomes for the instant relieved, and the force is transferred in a most extraordinary way through the two metals, so as again to enter into the dilute acid solution interposed between them (29), fig. 17, which in the act of transmitting it becomes decomposed. The water being an electrolyte, now gives up its oxygen to the zinc, and chemical action is directly established. In this operation, the two opposed electrical forces of the first series of particles acting on or toward each other in opposite directions, being necessarily equal, * are necessarily transferred in a reverse order, and constitute what we have termed (23) an electrical current. This current being once established, is perpetuated by the continued chemical decomposition of the water which immediately follows. It is, however, to be observed that the oxygen and hydrogen, under the form of water, are so powerfully held together that it is next to impossible to disunite these elements by the superior relation of the forces between the oxygen and the zinc taken alone; we require at the same time an abatement of force between the oxygen and the hydrogen themselves. Without this, the turning point of the new combination between the oxygen and the metal is scarcely reached, and no continued decomposition would ensue so long as the hydrogen of the water could accumulate on the zinc; but in the play of forces which thus arise in the voltaic circle, it is found that the rising of the force between the metal and the oxygen is attended by an opposite falling of the force by which the oxygen is united to the hydrogen; when decomposition ensues, the hydrogen is transferred to the surface of the copper or negative metal, where it is finally ejected (33).

47. Taking then the source of power on the voltaic pile as due to chemical action, we may conceive it to be divided into two parts: 1. The rising force between the metal and the oxygen of the water, and the consequent

* Rud. Elect. (98), p. 111.

falling of the force between the oxygen and hydrogen, the elements of the water. 2. The action which ensues when the change in the association of the elements is complete,—when the particle of oxygen leaves its hitherto associated particle of hydrogen and unites with the zinc. The first action is the source of the current, or otherwise of the tension, in the extremities of the pile in a disjointed circuit; the second action, by terminating at the instant of the first operation, brings succeeding particles into play, and so perpetuates the current. The immediate use of the second or negative metal is here apparent,—it opens a path for the progressive force or current to move in, and by which the conditions for the decomposition of the water are completed. Its direct communication by metallic connection is effectual in this respect. Electrolytic communication would not be effectual; an electrolyte would decompose, and obstructing forces would arise; moreover, the second or negative metal prevents hydrogen from accumulating on the surface of the active metal. The acid itself has little or no influence whatever in promoting the current force further than in facilitating the conduction of the water, and removing the oxide of zinc from its surface, so that it may not as it were choke up the way, and prevent fresh particles of metal from being acted on. The efficient power is in the decomposition of the water, indeed the presence of an electrolyte such as water is essential; its acts of conduction and decomposition are simultaneous, and the transmission of its elements in lines parallel with the current so important, that if this transmission stops, the current stops, if it be changed, the current changes. The water then of the acid solution being a decomposable and oxidating body, the attraction of the zinc for the oxygen becomes eventually greater than that of the oxygen for the hydrogen, but in combining with the oxygen puts into circulation an electrical current in a given direction, which direction is that of the transfer of the hydrogen

toward the copper or other negative metal. So that, as already seen (29), fig. 17, the current flows from the zinc toward the copper through the fluid below, and from copper to zinc through the metallic arc above, being at the same time consistent with the transmission of the oxygen from the copper upon the zinc in an opposite direction; the current, therefore, can pass in the prescribed line or circuit of direction, and yet favor the renewal of the condition upon the surface of the zinc, which commences by determining both the chemical combination and the succeeding circulation.

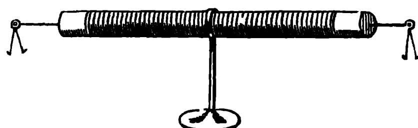
It will be perceived that, according to the Chemical Theory (46), the order of the series is considered as an association of two metals and one fluid, in the succession of metal, fluid, metal, &c., and not as in the order prescribed by Volta, of metal, metal, fluid: thus, taking the first plate of the pile (27) as being copper, we should, according to Volta, have a series of (copper, zinc, fluid,)—(copper, zinc, fluid,) and so on; whereas, by the Chemical Theory, the first copper plate would go for nothing, and we should have the succession (zinc, fluid, copper)—(zinc, fluid, copper,) &c., which is really the effective order already adverted to (31). The ingenious De Luc, in a most interesting analysis of the pile to be hereafter noticed (125), examined the several orders of the series or successions in which we may consider the two metals and fluid to be placed, and arrived at new and important conclusions as to its action,—he found the chemical and electrical effects in an inverse ratio to each other: without a fluid between the plates, the chemical power was little or nothing, so that the order which gave the greatest electrical development had the least chemical power, and that which developed the greatest chemical action had the least electrical power; hence, he arrived at the conclusion, that for the production of electrical effects the presence of a fluid conductor is not necessary, and it becomes only requisite to separate the associated pairs of

metals by a dry non-metallic conductor. This conclusion led to the construction of a pile not containing any fluid substance, a kind of pile which Volta in vain sought to obtain. Were a *perfectly* dry solid pile possible, there would probably be an end of the Chemical Theory: it would be purely a development of electricity by contact, and so far confirm Volta's views. It would constitute an apparatus liable to no derangement; always active; neither chemical action nor evaporation could affect it, and its operation would be perpetual and invariable.

48. It must be allowed that De Luc effected an apparent approximation to this result; he constructed of solid substances only, and with great success, what has been since termed an "electrical column." This column consisted of groups of silver and zinc, with interposed discs of writing-paper between each two pairs of metals. When twelve hundred pieces or discs of silver, zinc, and writing-paper of about three-fourths of an inch in diameter, are arranged in the order of silver, zinc, paper, we have an apparatus approaching as nearly as may be to a perpetual electrical machine of very weak power. An efficient and easy method of construction is to lay silver leaf on writing-paper, that is, to silver the paper, and then with a common punch of rather more than half an inch diameter, cut out a series of discs; a corresponding number of discs of common paper, and thin sheet zinc, should be provided in a similar way. These discs are now to be arranged within a tube of glass carefully varnished within and without in the order of zinc, paper, silver paper, with the silver upwards; then again, zinc, paper, silver paper, silver upwards, and so on; by which, as is evident, we obtain a succession in the order of silver, zinc, paper,—silver, zinc, paper, &c., the silver and zinc being always in contact. The glass tube in which these discs are placed is capped at each end with brass caps; through each of these passes a wire rod; being screwed through the cap, it compresses the series from each end, and serves at

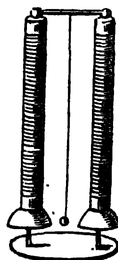
the same time as a conductor from each extremity of the column. When this apparatus is insulated and a delicate electroscope attached to its opposite extremities, the electroscope at the zinc extremity diverges with positive electricity, and that at the copper extremity with negative electricity. The annexed figure 19 is illustrative of the whole arrangement, supposed to contain from 1000 to 1200 discs.

Fig. 19.



49. The electricity of tension in the extremes of this column is often considerable. The positive and negative electricity is so rapidly and continually reproduced, that a light pendulous body may be kept in constant motion between the opposite poles of two united columns; these are usually placed on insulated brass bells, a metallic ball being suspended by a fine silk line immediately between them, as seen in the annexed figure 20, so that a continual chiming is the result; the action has been found to continue for many years; and it has been supposed that if the column were quite perfect, the motion would be permanent. This is, however, very doubtful.

Fig. 20.



Mr. Singer constructed a series of 20,000 groups of silver zinc and double discs of paper; the electrical power of which was so great that a light pith-ball electrometer diverged to a distance of two inches: an electrical jar containing fifty square inches of coating was charged by ten minutes' contact sufficiently high to produce a disagreeable shock across the shoulders and breast. The charge could perforate common paper when discharged through it, and fuse

about an inch of platina wire of the $\frac{1}{5000}$th of an inch in diameter.*

Zamboni, in 1812, introduced a new material into these columns; his piles consisted of paper thinly coated on one side with peroxide of manganese, and thin tin leaf on the other. Gassiot, with a series of 10,000 such discs, traced a slight chemical action on the hydriodate of potassa. Not the least chemical effect, however, could be traced with Singer's pile of 30,000 discs, upon De Luc's principle, notwithstanding its extraordinary electrical power.

50. The action of this apparatus, if taken as a dry series, would go far in confirmation of Volta's original view of the source of power in the pile (42); but then we cannot consider it as an unquestionably *dry* pile, because there will be always sufficient moisture in the intermediate paper, or other semiconducting substance interposed between the metals to convert it into a voltaic series of extremely low chemical power. In fact, when the paper is scorched dry by artificial heat, the apparatus does not act.

51. On reviewing the respective merits of the contact and chemical theories of the source of power in the voltaic pile, we find the facts in support of the chemical theory so overwhelming in every sense, that it is next to impossible to resist the conclusion, that chemical action is really the main spring of the whole machine. We find, for example, that chemical action does give rise to an evolution of electricity; that the current force is entirely dependent on it, that when the chemical action diminishes or ceases, the current also diminishes or ceases: when the chemical action changes, the current changes: when there is no chemical action, there is no current; no case has ever arisen of electrical current in the voltaic apparatus without chemical action, and there is every ground for supposing that the force termed chemical affinity is identical with electrical force. Then again, Faraday has shown, that for

* Elements of Electricity, pp. 461, 462.

a given quantity of water decomposed, a given definite quantity of electricity is transferred,—that the forces termed Chemical Affinity and Electricity are the same,*—so that the evolved electricity, and the decomposing electricity, is in amount precisely the same.

52. On the other hand, the contact theory is embarrassed by anomalies and improbabilities in the nature of things. It assumes, that a current is called into action, and maintained by metallic contact alone: here we must assume the force of contact to be so balanced as to produce in any voltaic circle an effect equal to zero, (17) and whilst the metallic substances in contact remain in every sense unchanged as regards their particles, they are supposed to actually discharge into each other; if any change of state or condition in their constituent particles were admitted, it would then become a chemical theory. The two metals, also by this hypothesis, are in opposite electrical states, the one being positive, the other negative, which states become at once destroyed by the intervening fluid, and recommence—but how? The whole effect of the apparatus is by the theory a disturbance and reproduction of electrical equilibrium; it in no way supplies an explanation of the production and evolution of electricity. The force which is supposed competent to produce a change of electrical state in the metals, in respect of each other, is yet incompetent by the hypothesis to maintain the new state induced; and without any consumption whatever of the generating force, we are obliged to assume the production of a current continually flowing on, against a constant resistance; this is not in the nature of things of which we have the least experience. There is no instance, in nature, of a production of power without a corresponding exhaustion of the source of the power. Now, in the chemical theory, the consumption of the original power is exactly equal to the force generated. If, as observed by Roget,

* Experimental Researches, 918, 783.

"there could be a power of giving impulse in a constant direction, without being exhausted by its own action, it would essentially differ from every other known power in nature; all the powers and sources of motion, with the operation of which we are at all acquainted, when producing their peculiar effects, become exhausted in the same proportion as those effects are produced." * Now Volta's electro-motive force continues unexhausted in the production of a never-ceasing effect.

53. The several effects of the pile as hitherto known may be thus classed:—

1st. Ordinary electrical effects: attraction; repulsion; the spark; shock, &c.

2nd. Physiological effects: action on the animal body before and after death; muscular motion and convulsive actions excited in a recently living body, and all the activity of life called back after death.

3rd. Chemical effects: decomposition and transfer of various bodies through solids and fluids; recomposition of decomposed bodies, &c.

4th. Heating effects: metallic wires made white hot or melted; metallic leaves burned, and inflammable matter ignited.

5th. Electrical and magnetic effects of current force: iron and steel magnetised; all metallic bodies rendered magnetic; the compass needle deflected from its meridian according to certain laws by any metallic wire joining the poles of the pile; evolution of Electricity by induced current force.

We propose to treat these several effects of the electro-motive apparatus in the order they here stand. It will first, however, be desirable to describe briefly the several philosophical instruments requisite to a clear experimental illustration, elucidation, and investigation of this wonderful physical subject.

* Library of Useful Knowledge, article "Galvanism," (113.)

CHAPTER III.

Apparatus employed in investigations of Voltaic action—The Condenser—Electroscopes and Electrometers—Cruickshank's Trough—Wollaston's Battery—Daniell's constant Battery—Smee's Battery—Nitric Acid Battery of Grove—Other Voltaic-battery arrangements—Voltameter by Faraday—Thermo-Electrometers—Various forms of Galvanometer—Wheatstone's Rheostat—Rheotomes and Reophores.

54. The principal philosophical apparatus requisite to an experimental investigation of voltaic electricity, may be classed as follows:—

1. Instruments for detecting and measuring small quantities of electricity.
2. Various improved forms of the voltaic series for the production of electro-motive force.
3. Instruments for measuring the heating and chemical powers of the series.
4. The galvanometer and other instruments for estimating current magnetic force.

INSTRUMENTS FOR DETECTING SMALL QUANTITIES OF ELECTRICITY.

THE CONDENSER.

55. The first and perhaps the most important of this class of instrument is the condenser, briefly described and explained in our Rudimentary Electricity, page 54. It was, as we have seen (15), by the aid of this instrument that Volta succeeded in demonstrating the electrical development incidental to the contact of dissimilar metals; it hence demands an attentive and further consideration.

Volta invented this very ingenious method of detecting minute quantities of electricity, otherwise insensible to the

most delicate electrometer, many years before his discovery of the pile. The instrument, as he constructed it, was of a very simple form,—it was merely a circular conducting plane, resting on a similar but imperfectly conducting plane beneath; such, for example, as a plate of baked wood or dry marble. When an insensibly electrified body is caused to touch the upper conducting plane, such is the influence of the imperfect conducting base on which it rests, that however small may be the quantity of electricity in the weakly charged substance, it enables the upper plate to absorb or take up the whole of it, and render it sensible to the electrometer; and this it does in virtue of the principle termed Induction;* that is to say, the imperfectly conducting base, backed by the influence of the great mass of the earth, determines the whole charge toward itself; yet it is sufficiently non-conducting, to prevent a dissipation of the charge. The charge, therefore, accumulates in points of the conducting plane, the nearest to the imperfect conductor below; when we remove the upper conducting plate, it ceases to be under the influence of the mass of the earth through the imperfect conductor beneath; and now the whole of the small charge which had become collected on it, is, as it were, set free, and in this way it is made sensible to the electrometer. The upper plate has been called the Collector, and the inferior plate the Condenser; Volta calls it a "conjugate" conductor. The title of his memoir on this ingenious instrument is, "sur les grands avantages d'une espèce d'isolement tres imparfait,"—a title every way expressive of the fact.

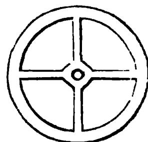
56. In applying this principle, electricians commonly employ two perfect conducting planes, one connected with the earth, the other insulated, and placed very near the first; the two surfaces being separated by some extremely thin insulating medium, such as varnished silk, or thin oiled

* Rudimentary Electricity, p. 15 (20).

paper, or in fact any insulator; a thin plate of air answers extremely well. The larger the conducting plates, the more powerful the condenser is thought to be. It is difficult to obtain plain circular or other conductors of any great size sufficiently light for the purpose. The following, however, is an efficient method of constructing such planes, and forming an efficient instrument.

57. Let rough circular segments of some dry light wood be glued together, so as to form a wide circular rim about an inch or more wide,—these pieces may be about the $\frac{1}{8}$th of an inch thick,—the grain and joints of the wood should be crossed in gluing the pieces together; when dry, let this circular rim be fixed in a lathe, and turned true both upon its external and internal circumference, and be then crossed by two light diameters to give it further strength, and to sustain the whole plate when fixed on an insulator, as represented in the annexed figure 21. The edges are to be covered with silver or gold leaf, and silvered or gilded paper is to be gently strained over the two faces. In this way we may obtain an extremely light flat plate, well adapted to this class of experiment; a plane of 18 inches diameter, constructed in this way, weighs about 8 oz.; a plate 10 inches diameter, 4 oz.: each disc should have a small brass plate fixed in the centre to receive an insulating or other handle.*

Fig. 21.

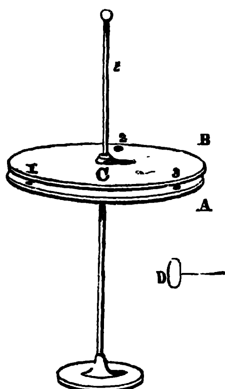


58. A powerful condenser may be obtained by the close approximation of two discs, such as just described, of about a foot in diameter, and arranged as in fig. 22, which will be found an available and simple form of this valuable instrument. The lower or condensing plate A is placed on a

* The paper, previously to being silvered or gilded, should be strained on a board; when silvered, should be allowed to dry: the circle is then cut out and applied to the face of the plate by paste round the wide rim of the circumference.

vertical conducting support, which may be a light brass tube terminating in a small circular disc of wood of about 3 inches in diameter, sufficiently large to sustain the plate easily at its centre C. The collecting or upper plate B, having an insulating handle C, is placed immediately over the lower plate, and rests upon three varnished glass pins, 1, 2, 3, inserted into the condensing plate A, near its circumference, at equal distances apart; these points project about $\frac{1}{40}$th or $\frac{1}{50}$th of an inch; they are made of small glass rods, about the $\frac{1}{10}$th of an inch in diameter, carefully varnished with shell-lac. We have in this case what may be considered as a plate of air of $\frac{1}{50}$th of an inch thick interposed between the two planes; the plates, in fact, will be separate the $\frac{1}{50}$th of an inch, consequently they will not touch.

Fig. 22.



When we desire to detect a small quantity of electricity in any given insulated body D, we apply D to the collecting plate B, and after removing D raise the collecting plate by its insulator handle *t* C, and then transfer it to the particular electroscope we have selected to examine the result. If the lower plate be insulated on a glass rod, the two plates A B become collectors and condensers reciprocally whenever we apply opposite electricities to each; as in the case of Volta's experiments (15), with insulated discs of metal.

59. The student must not imagine that the condenser exercises any magic influence upon the developed electricity by which it is either multiplied, or its force increased. The only active operation of the condenser is to absorb or take up, under the inductive influence of the condensing or conjugate conductor, small portions of electricity, to which

the collecting plate would be otherwise insensible, and which uniting in the collecting plate sensibly affects delicate electroscopes whenever the collecting plate is removed from the influence of the condensing plate opposed to it. The condenser, therefore, as is evident, no more multiplies electrical force, than a mechanical machine multiplies mechanical force ; all it does is to render a small force sensible through the intervention of secondary means; and, so far, like the mechanical machine, it may be considered to effect an application of power, which without it could not be applied at all.

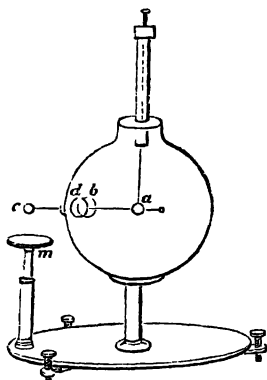
ELECTROSCOPES AND ELECTROMETERS.

60. The electroscopes and electrometers usually employed in conjunction with the condenser, are principally those described, (Rudimentary Electricity, chap. iii.) such for example as the single and double gold-leaf electroscopes, the electrical needle, the diverging reeds of Cavendish, the refined and sensitively suspended wires of Cavallo, Coulombe's balance of torsion, and the two-threaded or bifilar balance of the author. Volta himself employed an electroscope formed of two reeds of straw delicately hung within a glass receiver, and estimated the tension of the developed electricity by the small degrees of divergence imparted to them.

61. Of this class of instrument the finely-hung needle as used by Coulombe is one of the most sensitive. The following arrangement, represented in the annexed fig. 23, will be found efficient and available:—A light ball of cork or pith, *a*, carrying a fine electrical needle, *a b*, is suspended within a glass receiver by an extremely fine filament of unspun silk, as represented in the figure; the needle *a b* is constructed of a short piece of fine straw-reed terminating in a stout thread of glass varnished with shell-lac, or in a thread of lac or other insulator; at the end of this thread

is a disc of gilt paper, *b*, of about half an inch or more in diameter. The side of the receiver is perforated for the passage of an insulated wire *c d*, carrying at its inner extremity *d* a conducting disc similar to the disc *b*, fixed on the end of the needle; and the whole is so circumstanced as to admit of the two discs reposing lightly in contact with each other; the exterior extremity of the wire *c d* terminates in a small gilded ball or otherwise in a collecting plate, immediately under which is placed a condensing plate *m*, which by means of a sliding tube of brass may be brought as close to the collecting plate *c* as we please, or otherwise be removed from it by depressing the slide.

Fig. 23.



When the least quantity of electricity is communicated to the ball *c*, the disc *b* of the needle separates by repulsion from the disc *d* of the fixed wire *c d*. Coulombe, who constructed electroscopes with this kind of suspension, states, that "it only requires a force of the $\frac{1}{60}$ thousandth part of a grain acting upon a lever of an inch long to turn the needle through a whole circle or 360 degrees." Excited sealing-wax presented to the fixed rod *c d* at a distance of three feet caused the needle to diverge 90 degrees. The electroscope alluded to was less than six inches in diameter, the insulating stem of the needle being a thread of gum-lac 12 lines long; and the suspension silk 4 inches long, the whole did not weigh half a grain.*

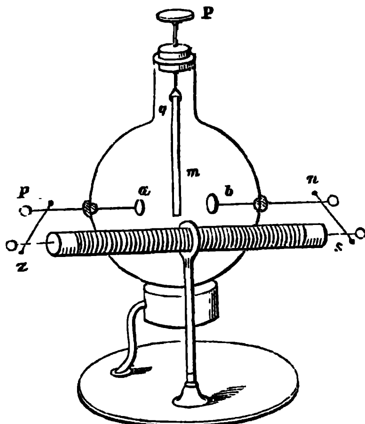
62. *Single-leaf Electroscope, with electrical column.* The electrical column explained and described (48) may be employed with advantage in increasing the sensibility of the

* Mémoires de l'Académie, for 1785.

gold-leaf electroscope, and in detecting the presence of minute quantities of electricity. Fig. 24 represents a compound instrument of this kind—at once simple and effectual.

A dry pile Z S (48) containing from three to five hundred pieces is sustained horizontally on an insulator immediately before a globular glass, in which is suspended in the usual way a single strip of leaf gold *m*; the glass is perforated on each side in points diametrically opposite, for the passage of two stout metallic wires *p a*, *n b*, completely insulated in passing through the glass: these wires terminate within in two gilded half balls of about half an inch in diameter; the suspended leaf *q m* hangs midway between their flat surfaces, the exterior extremities, *p n*, of the wires terminate in small gilt balls; these are connected when required by conducting cross wires *p z*, *n s*, with the opposite extremities *z s* of the electrical column. When a very weakly charged body is applied to the collecting plate P, the leaf *q m* becomes drawn to the positive or negative surface *a b* according as the electricity is negative or positive. The glass in which the leaf is hung is mounted on a curved rod, as seen in the figure, so as to allow of its projecting in such way as to afford the means of opening the cap which closes the lower end of the glass and drying the interior by artificial heat. If a condenser be placed in connexion with the plate P, either as a separate system or as resorted to by Volta (15) fig. 9, the instrument becomes extremely

Fig. 24.



valuable as a means of detecting minute quantities of free electricity. M. Bohnenberger, Professor of Physics at Tubingen, invented an electroscope of this kind in which the single leaf was suspended between the opposite poles of two separate dry piles. His instrument appears to have been so sensitive that a small stick of gum-lac, excited by cloth, affected the leaf at a distance of five or six feet.*

63. The author has occasionally substituted for the dry pile two small narrow coated phials united at their bases in a ring of wood, and insulated so as to stand horizontally in reverse directions. These being weakly charged, one positively, the other negatively, are very efficient in determining the motions of the suspended leaf in either direction; a mere residuum of a charge is sufficient. A very delicate instrument of this kind may be also constructed without the aid of the electrical column, *z s*, fig. 24, in substituting circular discs for the balls *p n*, and bringing two small coated phials, weakly and oppositely charged, to act upon the wires and discs *p a*, *n b*; the charging rods of the jars terminating in equal and similar discs. In this way, by varying the distance between the charged and neutral discs, we may impart to the half balls *a b*, on each side the leaf, any degree of positive or negative influence we require.

64. *Bifilar condensing Electrometer.*—This instrument, invented by the author, will be found extremely efficient in detecting and actually measuring small quantities of electricity.

A light needle *a b*, figs. 25 and 26, about five inches in length is suspended within a glass cylinder by two filaments of unspun silk; the filaments are set parallel to each other on each side of the centre of the needle at about the fifth of an inch apart, as represented in fig. 26. The centre portion, *c d*, of the needle is a short piece of varnished reed-straw about two inches in length; stout pieces of thread glass, *c a*

* Ann. de Ch., t. xvi.

and *d b*, varnished with gum-lac, or any other insulator, carrying light gilt discs, *a b*, of half an inch in diameter, are

Fig. 25.

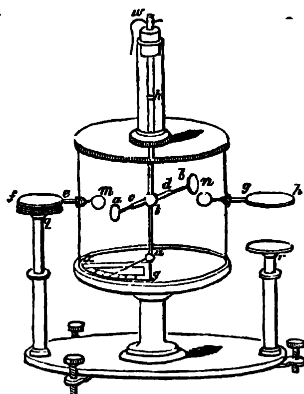
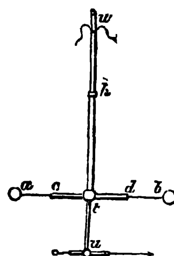


Fig. 26.



inserted into the opposite ends of the reed, the whole being in one straight line, and constituting a light needle of about five inches in length.

This electrical needle is sustained and suspended in the following manner:—there is a central wire-rod, *t u*, about three inches in length, terminating in small metallic balls, *t u*, about a fourth of an inch in diameter; the bifilar silks pass through a central horizontal hole in the upper ball *t*, and are secured above in a hole through the suspension wire *w*, by small pegs of wood; the central reed of the needle passes also through the ball *t* by which it is sustained in a horizontal position with sufficient friction; the lower metal bal' carries an index at *u* adapted to a graduated arc *x y*, at the bottom of the receiver, fig. 25, so as to show clearly the least amount of deflection of the needle from its quiescent position; this index is similar to the needle above, and is sustained in a similar way, being a short central reed terminating in a glass thread; there is a small hole in the under part of the ball *u*, to admit of its playing freely

about a fine steel central pin, and by which any undue amount of oscillation of the suspension is prevented, and the central position of the needle preserved; the dimensions of the suspension-rod *w* above, and the small ball *t* below, are so adjusted as to place the suspension threads about the one-fifth of an inch apart. The whole of the suspension apparatus, together with the needle, is sustained by a tube of glass about an inch in diameter fixed centrally in a glass plate or a plate of varnished wood, so that the needle with its index when duly adjusted may be easily let down and placed within the glass cylinder beneath, which hence becomes completely closed. To prevent the bifilar threads from crossing upon each other when the needle *a b* is deflected up to an arc of 90 degrees, there is a small stay of cork *h*, at their central portions *h*, and through which they pass. The needle, fig. 25, is represented in a state of divergence.

The glass cylinder is pierced at two opposite points of its circumference for the passage of two light metallic rods, *e m*, *g n*; these rods are sustained by cork plugs fitted in the hole in the glass; the glass is carefully varnished round these openings; the extremities of the rods, *e m*, *g n*, within the glass carry circular discs of gilded paper *m*, *n* corresponding with the discs *a*, *b* on the needle; their extremities without the receiver, support small collecting plates *e f*, *g h* of about two inches diameter. These collecting plates have corresponding condensing plates *q*, *r* fixed on small tubes of brass made to slide within exterior tubes, so as to be withdrawn or approximated to the upper condensing plate at pleasure, as indicated in the figure; the whole is fixed on a convenient elliptical base supported on three levelling screws; the fixed discs *m n* are so placed in respect of the discs *a b* of the needle, as to admit of the forces repulsing the needle in opposite directions, one being on the one side of the needle disc, and the other on the opposite side. The delicacy of this sort of suspension, if we employ filaments of silk suffi-

ciently fine, is quite wonderful, whilst the reactive force of the double silks is available as a measure.*

65. To detect minute electrical development by means of this instrument, as for example the electricity of metallic contact (15), we place the large condensing plate just described (58) on an insulated rod, the collecting plate resting above it in the way already explained (58); then, having made repeated contacts with the metallic plates, the subjects of experiment, and applied them, one to the upper plate A, the other to the lower plate B of the condenser, fig. 22 (58), we proceed to transfer the electricity of these plates A B of the large condenser to the small collecting plates *e f*, *g h* of the electroscope (fig. 25). If required we repeat this operation several times; we then remove the lower small condensing plates *q*, *r* by depressing the slides, and the needle of the electroscope diverges on one side with positive, on the other with negative electricity: when the amount of deflection of the needle is small, the quantity of electricity will be nearly as the angle of divergence in degrees of the graduated arc *x y*.

66. Many instruments have been invented as a means of further increasing the action of the condenser (58), and of multiplying the effect of Volta's original contrivance; these have been termed "doublers," "multipliers," and such like. Unfortunately their operation is very precarious and equivocal, inasmuch as they may themselves produce in the course of the manipulation the very developments of electricity they are supposed to detect; they are so far to be avoided. On similar grounds we avoid the use of thick varnishes, varnished silk, or varnished papers, which are sometimes interposed between the collecting and condensing plates, or with which the condensing plate was not unfrequently permanently covered (56); the least friction in the application of the collecting plate, or any other casual disturbance, would be a source of electrical excitation; Volta's original method of laying the collecting plate on an imperfectly insulating

* Phil. Trans. for 1836, p. 417.

base, such as baked wood, must be guardedly followed on the same principle. The safest construction is that just described (58), and the most unexceptionable means of enlarging the effect is by the transfer of the first collector to the small plate of a second condenser attached to the electrometer, as first contrived by Cavallo (65).

67. *Galvanoscope Frog.*—The prepared frog, as we have already seen (9), is very sensitive to electrical action; it is hence an extremely delicate electroscope when applied to detect minute quantities of animal electricity. The most approved method of preparing the frog for this purpose, is to cut it through the middle of the pelvis. The muscles of the thigh are then carefully separated, and one of the lumbar plexuses of nerves is to be divided as it passes out of the vertebral column. We have then the leg of the frog united to its long nervous filament composed of the lumbar plexus, and of its prolongation in the thigh, that is to say, the crural nerve. This preparation is directed by Matteuchi to be guarded in a varnished tube of glass, as shown in the annexed figure 27. In applying it, we hold the tube in the hand, and bring any two parts of the frog we wish to examine in contact with the nervous filament *p*, but at separate and distant points of it.

Fig. 27.



Contractions then ensue in the muscular portions within the tube. The disagreeable process of preparation, and the apparent cruelty of it, is very unfavourable to a general use of this test of electrical action, except under very peculiar circumstances. A variety of other forms of electroscopic instruments might be here quoted, but it seems unnecessary to our present purpose to extend this subject further. The student will find a full description of such instruments in our Rudimentary Electricity, chap. iii.

VARIOUS FORMS OF THE VOLTAIC APPARATUS.

68. *Cruickshank's Trough.*—This form of Volta's series was invented by Mr. Cruickshank of Woolwich, and was the first great step in facilitating the application of the pile as an instrument of physical research. We have already seen (30) that many inconveniences attend the apparatus as constructed by Volta, beside that its power was to a great extent limited; immediately therefore that the account of Volta's discovery reached this country in 1800, Cruickshank conceived the idea of converting the pile into a more permanently active and powerful apparatus. This he effected by means of fixed cells in a long narrow insulating trough, of which the several pairs of metallic plates themselves formed the partitions. He was thus enabled to interpose a mass of fluid between each pair of plates without the aid of any absorbing substance foreign to the experiment. This apparatus is represented in figs. 28 and 29. It consists of a

Fig. 28.

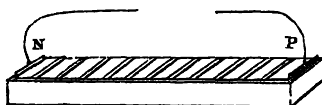
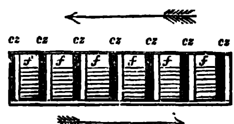


Fig. 29.



water-tight trough, P N, fig. 28, of baked mahogany, put together with white-lead; it is usually about 4 inches square and about 30 inches in length, and may contain a series of about 50 pairs of plates 3 inches square, soldered together and fixed parallel to each other by cement, in grooves cut in the opposite sides and bottom of the trough, as indicated in the figures; the order being (copper, zinc) (copper, zinc,) &c. The sides and bottom of the trough may be coated also with the same electrical cement.* This apparatus is excited by

* A good cement for this purpose is obtained by melting together in an earthen pipkin five parts of rosin and four parts bees'-wax, and then adding gradually two parts of powdered red ochre.

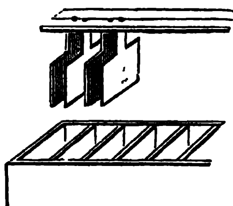
pouring water or a saline fluid into the intervening cells: we thus complete a series in the order of | c z *f* | c z *f* | and c z | as indicated in fig. 29; or, according to the chemical theory of the pile (44), in the order of | c | z *f* c | z *f* c | z. | The first copper plate c on the left, and the last zinc plate z on the right, fig. 29, not having the least influence in augmenting the power of the series (34). Remove these, therefore, or consider them merely as the doors of the pile (34); then we convert the series (c z *f*.) (c z *f*,) (c z,) &c., into | z *f* c | z *f* c | z *f* c | &c.

69. In this trough battery, as commonly constructed according to the contact theory, the negative pole or extremity has been called the copper pole, and the positive pole or extremity the zinc pole. The fluid generally employed for excitation, is, nitric acid of commerce 1 part, water 16 parts. Water acidulated with the sulphuric or muriatic acids may be also used. An effective acid solution is obtained by mixing 1 part nitric acid with 1 part sulphuric, in 60 parts water; or 2 parts sulphuric acid, 1 nitric, and 80 water. When a number of troughs are united, so as to obtain a series of two to three hundred pairs of plates, a battery of great power is obtained.

70. *Battery of the Royal Institution.*—The preceding arrangement, although very efficient, is still attended by some inconvenience, especially in removing the liquid from the plates. If the plates are large or numerous, the apparatus is very heavy. It is also difficult to renovate the surface of the zinc plates when covered with oxide. To avoid this, it was proposed by Dr. Babington to complete an independent cellular trough, with glass partitions, or partitions of some other bad conducting substance, to contain the dilute acid; and having arranged the metal plates under Volta's form of the "Couronne de tasses" (31), to place them in, or remove them from the liquid at pleasure. Porcelain troughs in Wedgwood ware, with partitions, have been employed with success; and for greater expedition in

immersing or removing the plates from the liquid, they were affixed to a bar of baked wood. This arrangement is indicated in fig. 30, in which two pairs of plates only are represented. The most perfect insulation would be a varnished trough of baked mahogany, having distinct flat cells of glass fitted in it, closely packed together.

Fig. 30.



The battery in the laboratory of the Royal Institution, placed at the command of Sir H. Davy in 1810, consisted of 200 porcelain troughs, each containing 10 double plates 4 inches square, the whole number of double plates being 2000; each pair of plates had a surface of 32 square inches taken together, so that the whole surface amounted to 128,000 square inches.

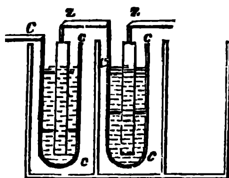
71. Mr. Children, F.R.S., had constructed about the same period, viz. 1809, several gigantic batteries, one consisting of copper and zinc plates, 4 feet high by 2 wide, excited by 120 gallons of fluid; and another of plates, 6 feet high by 2 feet 8 inch. wide. These plates were managed by suspension-pulleys and balance-weights. The power was such as to render 6 feet of thick platinum wire red hot. Napoleon I. had a great battery of the same kind constructed for the Polytechnic School, containing 600 pairs of plates about a foot square each, the whole battery exposing 600 square feet of surface.

72. *Wollaston's Battery.*—Some years after the construction of the former battery (70), Dr. Wollaston showed,* that by increasing the quantity of copper or negative conductor, the power of the series became augmented, and recommended that each cell should contain two copper plates, one on each side the zinc plate, so that both surfaces of the zinc plate might be exposed to the action of the copper surface. To effect this the copper plate is increased in length, and bent round and under the zinc plate, which

* Phil. Trans., 1815.

thus becomes placed in the interval between the folds, as indicated in the adjoining fig. 31, which is a mere diagram representing two pairs of plates with double copper in adjoining cells—the zinc plate of the one connecting with the copper of the following. The author of this little work, in a paper read at the Royal Society of Edinburgh, in December 1831, examined the law of action as regarded the distance of the plates and the quantity of the negative metal, and showed that not only is a great increase of power obtained by doubling the copper surface as in Wollaston's arrangement, but that the power is still further augmented by a still further increase of the copper surface, being principally limited by the increased distance at which it is requisite to place the additional plates of copper externally to the zinc.*

Fig. 31.



73. Many forms of the Voltaic battery upon this principle have been since devised. In some a series of cylindrical glass vessels have been used as cells, and the copper and zinc plates rolled round each other in a cylindrical form, or associated as simple cylinders, with interposed haircloth or other bad conducting matter, to prevent their touching. The American philosopher, Professor Hare, produced an effective battery of this description, which he calls a Deflagrator, from its intense heating power at the instant the several elements are simultaneously immersed in the acid solution. A similar helical battery was subsequently constructed for the University of France; it consists of 12 helical coils, each containing 60 square feet of surface. These coils, by appropriate machinery, can be lowered into or raised out of the acid solution at pleasure. The heating power of this battery is intense.

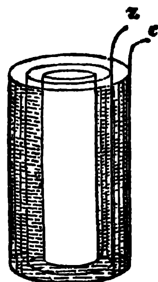
Pepys in 1821 constructed an helical coil, for the London

* Ed. Phil. Trans. vol. xii.

Institution, of enormous power and dimensions, consisting of a sheet of zinc and one of copper, each 50 feet long by 2 feet wide, wound round each other upon a cylindrical barrel, with intervening horsehair to keep the metals out of contact. This coil was let down by pulleys into a large vat containing 150 gallons of acid solution.

Mr. Hart, of Glasgow, observing the influence of the folded copper of Wollaston's arrangement, conceived the idea of converting the copper plate into an independent cell to contain the acid solution, placing the zinc plate within it. Several convenient arrangements of this kind, of various forms, have hence arisen, of which the simple cylindrical battery shown in the adjoining figure 32 is perhaps the best. It is evident that the copper surface c, in this battery, within and without the zinc surface *z*, may be considerably increased by additional copper cylinders concentrically placed in the cylindrical copper cell about the zinc.

Fig. 32.

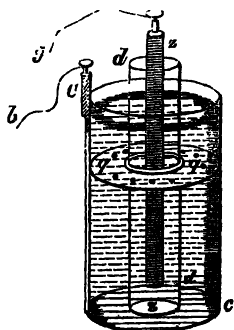


74. At the time of these several improvements in Volta's original apparatus, the theory, or rather principles, of its action were not well ascertained, whilst many important practical results remained undiscovered. The consequence was, that although the first effect of the new arrangements was powerfully brilliant, yet the action soon declined. The acid solution continuing to dissolve the oxide of zinc formed on the surface of the zinc plate (30), soon becomes exhausted of what may be called its constitutional power; it not only ceases to act further on the zinc, but its conducting power is much impeded. The hydrogen also set free at the negative plate (46) is very destructive of the battery power; it adheres to the surface of the negative metal, and so deteriorates its operation. It further tends to call up the zinc dissolved in the acid into its previous metallic state, and deposit it on the copper; so that we at last have

virtually two zinc plates opposed, instead of a zinc and copper plate. Beside all this, we have a local action on the impure zinc plate itself, by which it becomes rapidly destroyed, and portions of it are thus thrown out of action (30). These and other disturbing causes arising out of particular chemical actions peculiar to the especial case—to say nothing of the nitrous acid fumes found to arise from the cells—all tend to a destruction of power in the several forms of the voltaic apparatus just described. The discovery of the little action of dilute sulphuric acid on pure zinc, or on amalgamated zinc (30), is certainly effectual in removing some of these difficulties, but it does not remove them altogether.

75. *Daniell's Constant Battery.*—Things remained pretty much in this state up to the year 1836, and experimentalists still continued to struggle with the palpable defects of what have been since termed one-fluid batteries; when the late and much-to-be-lamented Professor Daniell, of King's College, London, discovered and applied an effectual means of preserving the power and continuing the action of the apparatus for a very considerable time. This battery, a single cell of which is represented in the annexed fig. 33, consists of an association of two metals with two fluids. We have first a copper cell, c c, about 3½ inches in diameter and 6 inches high. This cell has a perforated copper shelf *q q* near its upper end, with a hole through its centre, as seen in the figure. Within the copper cell is a second cylinder or cell *d d*, made of some porous substance, such as porous earth or animal membrane. Within this porous cell there is a solid cylinder of amalgamated zinc z z. The outer copper cell, c c, is filled with a saturated

Fig. 33.



solution of sulphate of copper, commonly called blue vitriol, having a little excess of acid added to it; and crystals of the same salt are heaped on the perforated shelf *q q*. The interior porous cylinder *d d*, within which is placed the amalgamated zinc, is filled with diluted sulphuric acid in the proportion of about 1 part acid to 20 parts water. The connexions with the opposite poles or electrodes are made by communications c *b* and z *g*, through the compressing screws at c z. Under this arrangement no action ensues before the circuit c *b g* z is complete—that is, if the surface of the zinc cylinder be effectually amalgamated with mercury (30). When, however, the circuit is made complete, then a vivid and sustained action commences, which will continue pretty constant for some eight to ten hours; after which time, the interior of the copper cell, c c, will be found coated with pure copper. The crystals of the sulphate of copper will have become dissolved, the solution will have become paler, and the dilute sulphuric acid will have become pretty nearly saturated with oxide of zinc. It now becomes necessary to renovate the exhausted elements before the battery is again fit for use.

76. The points of value in this arrangement, and the principles of its operation, are these. First, The hydrogen evolved (44) unites immediately in its nascent state with the oxygen of the dissolved oxide of zinc, and hence does not appear at all. Secondly, instead of zinc being revived by the hydrogen and deposited on the copper (74), to the great deterioration of the voltaic action, copper is revived and deposited, which is favourable to it. The porous cell separates the solution of copper from the zinc, and hence local action is prevented. No fumes of any kind arise, and the only limits to its action appear to be the consumption of the zinc, the consequent saturation of the dilute sulphuric acid in the porous cell D D, and the exhaustion of the copper solution in the external copper cell C C. This last is in great measure provided for by the

supply of the crystals of sulphate of copper on the colander shelf *q q*. The saturation of the zinc solution, and the consumption of the metal, can only be met by renewal; still the rapidity of this is not so great as to prevent a constant action in the battery for many hours. There remains still to be considered, as observed by Professor Daniell, the minor affinity of the copper for the acid. We can only meet this by using plates of platinum, and causing a perpetual renewal of them by the decomposition in the circuit of chloride of platinum; but this would be too costly.*

When a number of cells are united in the ordinary way (27), by connecting the zinc pole of the one with the copper of the other, we obtain a battery of immense power. Two dozen cells are ample for any ordinary purpose, especially when excited with hot solutions, which is found to increase the power considerably. The inventor of this very splendid arrangement has determined that for a given zinc surface the action is the same, whatever the diameter of the copper cylinder. The resistance to be overcome is as the distance between the metals directly and as their common section inversely.†

Many voltaic batteries upon this principle with two fluids have been since constructed. It is, however, to Professor Daniell's intellectual researches solely that we owe this great advance in Voltaic electricity.

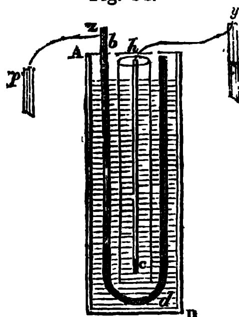
77. *Grove's Nitric Acid Battery.*—This battery, which is perhaps the most *powerful* combination yet arrived at, is based upon similar principles to those of the Constant Battery of Daniell. In this arrangement, the two fluids employed are dilute sulphuric acid and strong nitric acid, kept apart from each other by partitions of porous earthenware. The metals are zinc and platinum,

* Chemical Philosophy, p. 505.

† The common section is equal to the mean between the two surfaces.

The annexed fig. 34 represents one cell of this battery. The cells consist of troughs of glass or earthenware, A D, acid proof. Within each of these is placed a porous earthenware cell *h c*. This porous cell contains concentrated nitro-sulphuric acid—that is, nitric and sulphuric acids in equal parts. The exterior cell, or space, A *b d*, contains dilute sulphuric or muriatic acid in the proportion of one part acid to about three of water; *h c* is a plate of platinum foil immersed in the concentrated acid in the porous cell, and *z d* is a plate of amalgamated zinc bent round and under the platinum plate in the exterior cell A D, containing the dilute acid; *p z* is the connecting rod to the preceding platinum plate *p*, and *h y* the connecting rod to the next zinc plate *y*. The platinum and zinc plates are united by small clamp screws, and the series is so mechanically disposed as to exactly fit the successive cells.

Fig. 34.



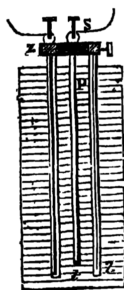
78. The action of this battery is wonderfully brilliant and powerful. The conducting power of the liquid is very perfect. The hydrogen evolved is immediately taken up by the acid in which the platinum plate is immersed, and decomposes it; so that powerful fumes of nitrous gas become evolved as the battery works; therefore the acid changes colour and becomes paler. There is no counter-precipitation of zinc, as in the one-fluid battery (74), nor is there any copper precipation as in the Constant Battery (75). There being no metallic precipitation at all, we have no counter-action; and since the nitric acid of this battery parts with its oxygen more easily than the solution of the sulphate of copper, in the constant battery, resistance is diminished and the power increased. Still, for extensive practical working, the Constant Battery of Daniell is more

convenient and is attended by less difficulty; and it is quite free from the offensive fumes of nitrous gas.

79. *Smee's Battery.*—An extremely simple and convenient arrangement of a one-fluid battery, by Mr. Smee, demands notice here. In this arrangement the inventor avails himself of a property of rough metallic surfaces, to throw off or to get clear of hydrogen gas deposited on them; smooth surfaces cannot do this, and this constituted one source of difficulty in the progressive march of Voltaic combinations (74).

The arrangement is very easy and simple. It is represented in the annexed fig. 35; in which s *t* is a plate of silver, covered with a finely divided powder of platinum, and which Smee calls platinized silver. This plate is fixed between two plates of zinc *z z*, through the intervention of a bar of wood. The zinc plates are united and secured against the wood by clamps passing over the bar from plate to plate. The platinized silver is prevented from touching the zinc by intermediate pieces of cork covered with sealing-wax. The connecting wires of the opposite electrodes are through the points z s, one from the zinc plates, the other from the platinum. The metals thus arranged are placed in any glass or other appropriate vessel containing dilute sulphuric acid, in the proportion of 1 part acid to 7 parts water. When so placed, hydrogen is given off freely with a hissing noise, and a large quantity of electricity is evolved. The characteristic of this battery is its great simplicity and power. Platinum may be employed, or palladium, but the surface must be roughened by sand-paper. When silver is employed, the surface is first brushed over with a little strong nitric acid; this gives it a frosted appearance; it is then washed and placed in dilute sulphuric acid, containing a few drops of nitro-muriate of platinum. On introducing a small plate of zinc placed in a porous tube containing dilute sulphuric acid, and making contact between

Fig. 35.



the metals, the platinum is deposited upon the silver, and constitutes what has been termed platinized silver.

Iron is effectual when rubbed over with nitro-muriate of platinum. Mr. Smee, considering the mechanical action of the rough surface in clearing the plate of hydrogen gas, has termed this arrangement "the chemico-mechanical battery."

From the dense atmosphere evolved between the metal plates, Grove recommends the use of platinized gauze, so as to bring the plates nearer together.

80. The following brief reference to, and enumeration of, several valuable forms of the voltaic apparatus may not be altogether out of place in concluding this notice of successive improvements on Volta's original pile.

Kemp's Pile—consists of a series of zinc plates, fluid mercury, and dilute muriatic acid. The fluid mercury and dilute acid are placed in a shallow box-wood cup. The zinc plate is held beneath the cup by a central wire passing up into the mercury. A series of these combinations are placed one over the other, so that the zinc plate under the cup of one becomes immersed in the dilute acid of the cup beneath. We thus obtain the series—zinc, mercury, dilute acid. In this pile the negative metal is a fluid. The arrangement, however, was not found so efficient as anticipated.

Kemp's Amalgam Pile.—The mechanical arrangement is similar to the former, but here the plate below the wood cup is copper, and an amalgam of zinc and mercury in a fluid state is substituted for the mercury. The liquid is dilute muriatic acid and muriate of soda. This pile was found active; the negative metal being a solid, it has the great advantage of remaining a long time in action. Little or no oxide is formed in the amalgam, the particles of zinc being taken up immediately by the acid. The discovery led the way to amalgamated zinc plates (30).

Bunsen's Battery.—In this arrangement carbonaceous matter is substituted for the platinum of Grove: the principles otherwise the same.

Schonbein's Battery.—On Grove's plan; peroxide of lead is used instead of nitric acid.

Grove's Gas Battery.—Oxygen and hydrogen gases are employed with strips of platinum foil.

Water Battery.—After Cruickshank: an extensive series, with pure water. The most perfect are those by Cross, Noad, and Gassiot. The battery by Cross contains 2400 pairs of plates, the cells well insulated. Noad's battery consists of 500 cylindrical pairs in green glass vessels. Gassiot's battery extends to 3520 cylindrical pairs, placed in cells of varnished glass, and insulated on varnished glass pillars.

Sturgeon's Battery.—Materials are, cast iron cylindrical vessels, cylinders of rolled zinc amalgamated; and dilute sulphuric acid.

Mullins' Sustaining Battery.—This is a double-fluid battery, on the same principles as Daniell's. Materials are amalgamated zinc, copper, solution of sulphate of copper, and solution of muriate of ammonia.

Leeson's Battery.—Is a Daniell's arrangement, with bichromate of potassa instead of sulphate of copper.

Walker's Constant Battery.—After Daniell. An earthenware jar is employed, its interior being coated with a precipitate of copper, by which it acquires a rough surface, favourable to the throwing off hydrogen. This is an extremely clever and valuable piece of apparatus.

Hare's Battery.—Each pair consists of a copper and zinc plate united at their upper edges, the other edges are set in grooves in a trough; the plates are packed very closely together. The trough containing the plates is connected longitudinally with a second trough, containing the acid solution; the two troughs turn upon revolving centres, so that the fluid may be turned from the one into the other.

Young's Battery.—After Hare's battery: the plates are so arranged, that a copper square comes in between each pair of zinc squares, and a zinc square between each couple of

copper squares. Asserted advantage is, that an equal effect is produced with one-half the quantity of copper.

Faraday's Arrangement.—Similar to Hare's: the plates are as in Wollaston's battery, zinc and double copper, but the copper is so bent as to come extremely near the zinc, being prevented from touching by an intervening bad conductor; an extensive series are closely packed together and plunged, when required, into a trough without partitions containing an acid solution, insulating cells not being in this case necessary.

Battery by Van Melsen of Maestricht.—The copper of each pair envelopes the zinc of the following pair, as in Wollaston's battery, but the plates of zinc and copper are much nearer, being only $\frac{1}{15}$th of an inch apart, with small pieces of cork between: the plates of copper of the consecutive elements are separated by glass plates. The series is set in a frame and plunged into an acid solution when required. The zinc is carefully amalgamated. The arrangement is very efficient and powerful.

81. In reviewing our experience of these several modifications and improvements in Volta's original invention, we arrive at the following general conclusions:—Of all the solids, metals and charcoal are the most efficient for the purpose of a voltaic series; of fluid substances, those which produce the greatest chemical action upon the solids are to be preferred. The metal zinc, either in a pure state or amalgamated with mercury, is upon the whole the best adapted as the positive element. The smoother the surface the better. Rolled zinc plates are preferable to cast zinc. For the negative element; silver, copper, iron, platinum, or platinized silver, or carbon, have been found the best. The surface of the negative element should be at least twice as great as the surface of the positive element, and the negative element should surround, and be as near as possible to the positive. The fluids may be pure water, or strong saline aqueous solutions, or concentrated or dilute mineral acids,

or alkaline solutions. The power of the combination with acids is in proportion to the affinity of the metal for oxygen. As a general principle, every oxidable metal is positive in relation to every other less oxidable. Volta, as already observed (16), determined the order of a series of metals, in which each metal was positive to the succeeding. The following is an order of succession by Davy, in which each substance is the positive element to either below it, and the greater the distance between any two elements, the greater generally will be the electrical development.

1. Potassium and its amalgams; 2. Barium and its amalgams; 3. Amalgam of Zinc; 4. Zinc; 5. Cadmium; 6. Tin; 7. Iron; 8. Bismuth; 9. Antimony; 10. Lead; 11. Copper; 12. Silver; 13. Palladium; 14. Tellurium; 15. Gold; 16. Charcoal; 17. Platina; 18. Iridium; 19. Rhodium.

As we have seen, however, (20), certain exceptions may arise in given cases of alkaline fluids and hydro-sulphurets.

82. Potassium, barium, &c., and such kinds of metals are next to impracticable as solid elements of the Voltaic apparatus. The following is a series of the available metallic elements and charcoal in the order of their electrical, or positive and negative, powers:—1. Zinc; 2. Iron; 3. Tin; 4. Lead; 5. Copper; 6. Mercury; 7. Silver; 8. Gold; 9. Charcoal; 10. Platinum. In this series a combination of platinum and zinc is more powerful than copper and zinc; yet cast-iron, as being a combination of iron and carbon, would be a very powerful combination with zinc, as found by Sturgeon, (80), although iron and zinc, taken as pure metals, are very near each other in the scale. We cannot, therefore, in every instance take the distance between the elements as a measure of the power of the combination, without, at the same time, considering very numerous exceptions. Indeed the power and the place of the substance in the series is, at least, very dependent on the exciting fluid. Faraday found nickel negative to antimony in strong nitric acid, but positive to it in dilute nitric acid, and gives a table of ten metals in seven

different solutions.* Mons. de La Rive, on this principle, proposes to construct an order for metals in reference to different exciting fluids, and to determine a zero point in each for the metal of the least chemical action. The following is an example in relation to muriatic acid:—1. Zinc; 2. Copper; 3. Silver; 4. Antimony; 5. Gold; 6. Platinum; 7. Rhodium; 8. Plumbago. Plumbago is here the lowest substance; so that very much yet remains to be completed in this branch of Voltaic electricity. Faraday observes, that to perfect lists of this kind we require to determine numbers, expressing the relative exciting force, counting from the zero point. Such an arrangement of the preceding series would be:—Plumbago, (zero); Rhodium, 1; Platinum, 2; &c. &c., and so on, in an inverse order to the preceding, supposing the relative numbers correctly determined.

INSTRUMENTS FOR MEASURING THE HEATING AND CHEMICAL POWER OF THE VOLTAIC APPARATUS.

83. The heating power of the voltaic battery is best measured by its effects on metals. The degree of incandescence produced by the current, in a metal such as platinum for example, very difficult of fusion by ordinary fire, will frequently help us in estimating the comparative power of a given voltaic series. As observations, however, of this description afford rather distant approximations, more refined means of estimating the degree of heat or incandescence has been sought for through the medium of philosophical instruments. The first instrument on record in the history of electricity, adapted to this end, is the Thermo-Electrometer, invented by the author so long since as the year 1820,† since which period it has come into general use; and having been repeatedly quoted and dealt with by the British and

* Exp. Researches, vol. ii. p. 86.

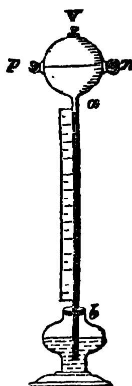
† Effects of Lightning, &c. &c. Letter to Vice-Admiral Sir T. B. Martin. Nicol and Co. London, 1823.

Continental philosophers,* it is essential to give here a brief account of it.

84. *Thermo-Electrometer.*—The instrument is virtually a Sanctorius air thermometer, with a fine metallic wire passed air-tight through the bulb. When an electrical discharge or current traverses the wire it becomes more or less heated, the air in the bulb expands, and the fluid, ascending or descending along the scale, shows the force of the current in terms of the heat of the wire.

The original form of the thermo-electrometer is represented in the adjoining fig. 36, in which *a, p, v, n* is the thermometer glass ball, of about $3\frac{1}{2}$ inches in diameter, and *p, n* a fine metallic wire passing air-tight across its centre, being secured in brass flanches, *p, n*, cemented over holes drilled through the glass; *a, b* is the thermometer tube and scale, the lower extremity of the tube being immersed in a cistern, *b*, of coloured fluid. A small quantity of air is first expelled from the ball by heat, the tube is then passed through a cork into the cistern *b*, the fluid ascends along the scale as the ball cools. The position of the fluid is finally regulated by a small screw valve at *v*, cemented over a hole drilled in the ball, and which can be opened and closed at pleasure. When an electrical discharge or current is passed through the wire, *p n*, the fluid descends along the scale *a b*. The scale is moveable for a short distance up or down upon the tube, so as to adjust the zero point to the precise place of the fluid. The method of securing the wire, *p n*, passed through the ball, is represented in fig. 37, in which the curve, *g k m p*, represents a portion of the glass ball; *k m d*

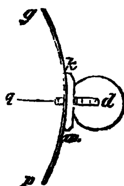
Fig. 36.



* De la Rive, Traité de l'Electricité, p. 31; Reiss, Ann. de Chimie, t. 69, Prem. Ser.; Faraday, Exp. Researches (344), vol. i. Davy, Physiological Researches, vol. i., p. 12.

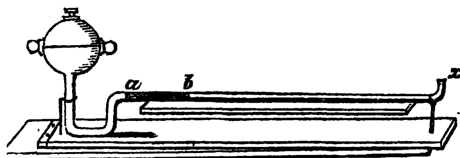
is a brass flanch, made to the curve of the glass and having a projecting stud, *d*, on which is cut the thread of a screw for receiving a flattened brass ball *d*, the ball being screwed on the stud *d* against *k m*, secures the opening in the glass air-tight. A fine hole is drilled through the flanch and stud at *d*, for receiving each end of the wire *p n*, (fig. 36), as at *q d*, (fig. 37), and the wire is firmly held in its place by the pressure of a small peg of wood inserted between the wire and the brass. The small valve, *v*, is constructed and applied much in the same way.

Fig. 37.



85. This form of the thermo-electrometer, although very sensitive and efficient, is somewhat troublesome and inconvenient; it was hence changed at first to the form represented in the annexed fig. 38, in which the indicating tube

Fig. 38.

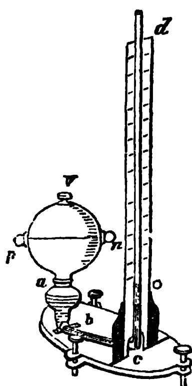


and scale were bent at right angles to the thermometer ball, and being secured on a hinge-jointed board, could be either set horizontally or at a greater or less degree of inclination. In this form of the instrument a moderately short column of coloured fluid only, *a b*, was employed by way of an index.

86. The form of this instrument, given in the Transactions of the Royal Society for 1827, as adapted for the purposes of ordinary electricity, and in the Edinb. Phil. Transactions for 1832, as adapted to voltaic electricity more especially, is represented in fig. 39, having been found upon the whole the best and most convenient for all practical purposes. Here the glass ball, *a p v n*, which is about

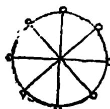
four inches in diameter, is screwed upon a small glass cistern, *a b*, containing coloured fluid, so as to be easily removed. The cistern is united by welding to a long thermometer tube, *b c o d*, bent so as to be parallel with the cistern and ball. The whole is sustained in a vertical position by a graduated scale *d o c*, and a small elliptical base set on three levelling screws, as shown in the figure, the scale being united to the base at *c*; it is evident that the zero of the scale, as at *o*, will be at the same altitude as the level of the fluid in the cistern *a*, and that the precise correspondence of the fluid with the zero point may be regulated by opening the valve at *v*. The scale *o d* is divided into tenths and twentieths of an inch; the fluid for noting the degrees of the scale is one part rectified spirit with three parts distilled water, coloured by a small quantity of tincture of cochineal.

Fig. 39.



87. With a view of a speedy comparison of the effects on different metals, or otherwise varying the amount of the visible effect produced by the discharge, when the heating power is considerable, glass balls are prepared containing two, three, or four wires of different metals, as represented in the annexed fig. 40, which may be taken as a horizontal middle section of the ball, showing the wires crossing each other in the centre. The dimensions of the wires may vary from the $\frac{1}{50}$th to the $\frac{1}{300}$th of an inch in diameter. For the general purposes of an electrometer, a platinum wire of about the $\frac{1}{80}$th to the $\frac{1}{100}$th of an inch in diameter may be employed. A very *fine* platinum wire of the $\frac{1}{500}$th of an inch or less in diameter, turned into an helical coil, so as to increase the length, and placed in the ball, renders the instrument sensitive to an extremely small force,

Fig. 40.



indeed it is difficult, with such means at our command, to assign a limit to this sensibility.* Faraday, at the meeting of the British Association at Oxford, in 1832, first discovered the heating effect of the magneto-electrical current through the delicate action of this instrument.†

88. Another form of the instrument, fig. 39 (86), similar to that given, fig. 38 (85), has been occasionally used by the author. In this the thermometer tube is bent forward at *o*, so as to be set horizontally, or at some given degree of inclination; but it does not appear to possess any advantage over the form just described.

89. A very general use of the instrument, as described in fig. 39 (86), has verified its perfect efficiency as an instrument applicable to the measurement of voltaic and ordinary electrical discharges; in short, there is no well authenticated law of electrical action with which its indications do not coincide. It will be, however, requisite, in certain cases of weak electro-motive power, to take into consideration certain laws of electrical conduction as regards the wire in the ball, and which will be hereafter explained in treating of the heating effects of the voltaic apparatus. In some particular cases of weak electro-motive power, a fine wire of silver may be preferable to a wire of platinum, from the circumstance of its high conducting power admitting

* The author obtained, with an helical coil of very fine wire in the ball, an elevation of five degrees of the fluid by a shock from the gymnotus. Dr. Davy, in employing an extremely thin wire of platinum, drawn down by Wollaston's method (Phil. Trans. for 1813, p. 114), found it "strongly affected" by the torpedo, even distinctly by weak fish, "when it formed part of a circle in connection with the galvanometer. I have seen it (he says) affected alone, the galvanometer affording no indication." He also states, that "the delicacy of the instrument was so great, that the spirit in the stem was not only moved by a single spark of the electrical machine, but even by a single voltaic circle, consisting of a copper and zinc wire, the former 1-25th, the latter 1-50th, of an inch only in diameter, excited by dilute sulphuric acid."—Physiol. Researches, vol. i., p. 12.

† Exp. Res. (344) vol. i.

of a more free transmission of the current force, as may be inferred from the experimental investigations relative to this instrument printed in the Transactions of the Royal Society of Edinburgh for 1832. The indications of the electrometer may be always relied on as a measure of the force of a voltaic combination, provided we employ a wire in the thermometer ball which will freely transmit the current: this may be determined experimentally by observing the effects of a given battery in three or four portions both separate and combined. If the indications of the instrument correspond with the increased power,—that is, if the indicated degrees of the scale be twice as great when the battery surface is doubled, and three times as great when trebled, &c., supposing the metals to operate as a single pair of plates,—we may then safely rely on the operation of the instrument as a measure of the current force for certain given voltaic combinations.

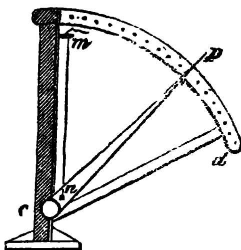
90. Mons. Reiss, of Berlin, and some other of the continental philosophers, not content with the instrument as originally constructed, have thought it worth while to resort to another form of it, but which is virtually the same as that described, (85), fig. 38. In this the index tube, fig. 38, terminates at its extremity, *x*, in a small cistern. A coloured fluid is placed in this cistern, and allowed to occupy a certain space in the tube, say up to *b*. The heating effect is measured by the retreat of the fluid into the cistern. Any degree of inclination is given to the instrument by a means similar to that described in fig. 38. This form of the instrument is employed by Mons. Knochenhauer, and is the form figured by Pouillet and Reiss in their respective works.*

91. *Thermo-Electrometer*, by M. Gaspard de La Rive. This is a very simple and ingenious contrivance. A fine

* Pouillet, Elements de Physique, and Reiss, Statical Electricity. M. Reiss seems to have confounded the instrument with the air electrometer of Kinnersley, in which the mechanical violence of an electrical shock is tested by an explosion between two balls in a confined space of air. This is evidently a misapprehension.

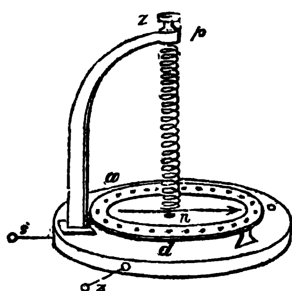
platinum or other metallic wire, *m n*, fig. 41, is fixed at one extremity, *m*, to a vertical bar of wood, being one arm of a quadrantal arc *m p d*, its other extremity, *n*, is attached, very near the centre of motion, to a sensitive lever, *c n p*, moveable about the centre of the arc, *m p d;* hence the least expansion or contraction of the wire by heat is indicated by a fine point, *p*, moving at the extremity of the lever upon the graduated arc *m p d*. When an electrical discharge or current traverses the wire, the index, *c p*, measures the force of the current in degrees of the scale.

Fig. 41.



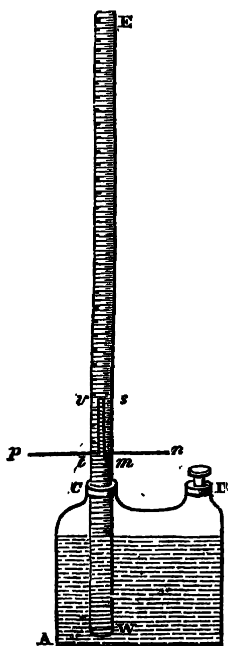
92. M. de La Rive's *thermo-electrometer*.—This instrument is simply the thermometric helical coil of Breguet attached to a fixed point, *p*, fig. 42, and carrying a needle, *n*, at its lower extremity, moveable over a graduated circle, *a o d*. The helical coil, *p n*, consists of a mechanical combination of three extremely thin straight metallic laminæ of different metals, superposed one on the other; the metals employed, are gold, platinum, and silver. The unequal expansion of the three metals by heat causes the coil to turn and return about its axis with the least change of temperature; a fine platinum wire is soldered to the lower extremity, *n*, of the coil, which plays freely in a small cup containing mercury. The connections are made with the battery through this mercurial medium and the metallic point *p* above, along the line *z s*. The slightest elevation of temperature is immediately indicated on the graduated circle.

Fig. 42.



93. *Volta Electrometer or Voltameter.*—This instrument is based upon the effects of chemical decomposition. Faraday has shown that when water is subjected to the influence of the voltaic current, the quantity decomposed is directly proportional to the quantity of electricity it has conducted. If, therefore, the two gaseous products, oxygen and hydrogen (47), decomposed in a given time, be carefully collected, and the volumes accurately measured, either separately or conjointly, we at once obtain a measure of the quantity of electricity, by the agency of which they have been set free from their previous combination under the form of water. Several contrivances have been resorted to with a view of collecting and measuring the gases evolved in the decomposition of a given quantity of water during a given time, say one minute; or otherwise the time in which a given volume of gas has been collected.

Fig. 43.



The annexed fig. 43 represents a form of Voltameter which may be considered as being upon the whole the best adapted to general practical purposes. In this figure, A D is a closed cylindrical glass vessel, about four inches in height and something less in diameter. It has two necks or openings at C and D. A glass tube, W E, about sixteen inches in length, and about eight-tenths of an inch in diameter, is inserted and closely fitted by grinding through the neck C. The opening or neck D is fitted in a similar way, with a ground glass stopper, removeable when required. The glass tube W E is pierced just above its insertion into the bottle A B, in two points, *t m*, immediately

opposite each other, for the reception of two wires of platinum, *p t*, *m n*, which are welded in the glass, and terminate within the tube in two slips of platinum foil or thin plate, *t v*, *m s*. The tube is graduated above this along its whole length, indicating measured volumes of hundredths of a cubic inch.

94. The instrument is prepared for use by filling the bottle A D, through the neck D, with distilled water, acidulated with pure sulphuric acid, in the proportion of one acid to ten water; when filled the stopper is replaced, and the whole inverted so as to fill the graduated tube W E, after this it is again reverted, and the neck D left open. The instrument is now ready for use, and being introduced into the current, as at H, fig. 18 (39), the current is caused to flow from *p* to *n*, fig. 41, through the acidulated water in the tube, between the platinum plates *t v*, *m s*. The quantity of electricity which has passed in a given time will be measured by the volume of gas evolved and collected in the upper portion of the tube W E. One division of the graduated scale is called a degree of electricity. The use of the instrument demands much care and attention. In estimating the absolute quantity of electricity we must take into consideration the temperature and pressure of the atmosphere, and apply a correction for moisture, a simple Table for which is given in Faraday's work on Chemical Manipulation, so as to reduce the observed volume of gas collected to a constant standard.* We have further to consider that the quantity of gas disengaged in a given time depends not only on the power of the voltaic apparatus, but on the degree of acidity of the water, also on the extent of the platinum plates, and their distance apart. In all experiments, therefore, of a comparative kind, these elements must be precisely the same.

95. When accurately employed, the Voltameter is considered

* Edition of 1830, p. 376.

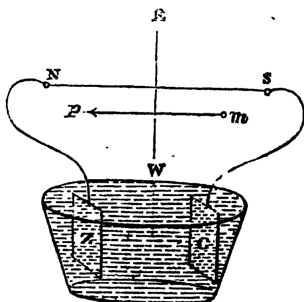
by Faraday to be the only instrument we have, as an *absolute measure* of voltaic electricity. It is quite independent of variations in time or intensity, or intermissions of action, and records and reveals satisfactorily the quantity of electricity which has passed through it. On this account it has been termed "*Volta Electrometer,*" or Voltameter.*

Instruments for Measuring the Force and Determining the Direction of the Voltaic Current.

96. The magnetic effects of the voltaic series have been already adverted to (53), and the property possessed by any metallic wire, traversed by the electrical current, of causing the magnetic needle to deviate from its meridian, according to certain laws, has been fully treated of in our "Rudimentary Magnetism," chap. iii. We shall, therefore, treat this subject here only so far as is requisite to place the class of instruments now under consideration in a clear and intelligible light, leaving further explanation to a future part of the work (Chap. VII.)

Let the adjoining fig. 44 be a simple circle, such as before explained (33), fig. 17, and C S, N Z a closed circuit of metallic wire, uniting the plates *z c*, a portion of which, S N, is quite straight, and placed in the magnetic meridian, N being the north, S the south points, and E, W, the east and west points. Let *m p* be a delicately poised compass-needle, moveable upon a centre, and placed under the wire S N. Then supposing that, at the instant the circle is complete, an observer be looking directly over the wire

Fig. 44.



* Faraday, Experimental Researches (739), vol. i. p. 27.

and needle, in the direction S N, that is toward the north, he will see the south pole *m* of the needle move toward his right hand, that is toward the east, and consequently the north pole *p*, toward his left hand, or toward the west, and if the current be sufficiently powerful the needle *m p* will stand across the wire S N, so as to rest at right angles to it. Such is the case when the current passes over the needle, in the direction of its meridian from south to north. When, however, the direction of the current is reversed from N to S, that is to say, supposing the plates *z c* to change places, then the reverse of these directions of deviation in the needle *m p* takes place. In fact, the extremity of the needle next the copper plate C will always go to the right hand, the current being parallel to and above the needle. If now we place the needle *m p* over the wire S N, so that the current may flow under the needle, then we have the reverse of all the former directions of deviation, the end of the needle, next the copper, C, will now always pass to the left hand. Such are the elements upon which the class of instruments termed galvanometer, electromagnetic multiplier, rheometer, and rheoscope are based, and which as furnishing a very delicate means of detecting and measuring current force, both as to intensity and direction, are of the utmost importance to this department of physics.

97. The following nomenclature adapted to instruments of this kind expresses concisely the several operations involved.

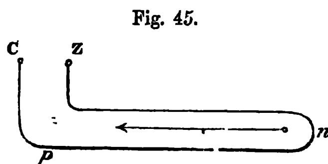
According to this nomenclature, any apparatus originating an electrical current is termed a "Rheomotor," from the Greek of ῥέω, to flow, and *moveo*, Latin, to move, whilst the straight wire S N, fig. 44, has been termed "rheophore," from the Greek of ῥέω, to flow, and φορέω, to bear, that is to say, as being the bearer or carrier of the current. The whole circuit, C S N Z, has been on a similar principle termed the rheophoric circuit. An instrument for merely detecting the existence of an electrical current is termed "rheoscope," from the Greek of ῥέω, to flow, and σκοπέω, to see. If

applicable to the measurement of the current force, it is then termed "rheometer," from ῥέω and μετρέω, to measure: this term is used by the French philosophers, instead of galvanometer.

An instrument by which the direction of the current in the circuit can be changed, or reverted, as from S to N, and N to S, is termed a "rheotrope, from ῥέω and τροπός, of τρέπω, to turn. An instrument by which a current can be periodically interrupted, is termed a "rheotome," from ῥέω and τέμνω, to cut off. An instrument by which the current is maintained or brought to any given degree of force is termed "rheostat," from ῥέω and στάω, to stand or remain. Such terms are expressive and concise, and should be generally employed in preference to many in common use, such, for example, as the term galvanometer, being much more consistent with an exact philosophy.

98. *Rheoscope* or *Electromagnetic Multiplier*, or *Galvanoscope.*—The most elementary and simple form of this instrument, would be that just indicated fig. 44, that is to say, a simple rheophoric wire with a magnetic needle, placed either above or below it. It may be, however, easily inferred (96), that since a current flowing *above* or *below* a magnetic needle in opposite directions, deflects the needle in the *same* direction, we necessarily obtain a double force, in exposing the needle to the simultaneous operation of both currents. This is easily effected by placing the needle within a bent wire, in the way shown in the annexed fig. 45, and establishing a current, C *p n* Z, through the wire: such an arrangement constitutes the second most simple form of rheoscope. If we imagine the wire to have many convolutions between its extremities C Z, as shown in the annexed fig. 46, and the needle to be placed within these convolutions, we

Fig. 45.



necessarily multiply the current influence upon the needle, in proportion to the number of turns or times which the current flows round the needle. We have only to cover the wire with silk or some bad conducting substance, so as to effectually cut off metallic contact between the convolutions, and compel the current to circulate about the needle. This constitutes the form of rheoscope, generally termed "electromagnetic multiplier." The needle, in this kind of rheoscope, may be a light magnetic needle, about three inches in length, suspended within the coils by a fibre of silk, passing through a small quill or other bad conducting tube, in the middle of the length of the upper portion of the coil. Two needles are usually employed, with their poles in reverse directions, as represented in the adjoining fig. 47, the whole being so contrived as to admit of one of the needles, *b*, being above, and the other, *a*, within the convoluted wire: this materially reduces the directive force of the earth on the needles, and renders the whole as a compound system almost astatic.* Hence the magnets become more obedient to the current, whilst the addition of the second needle still further multiplies the effect. This compound arrangement constitutes the next and last form which has been given to this class of voltaic instrument.

Fig. 46.

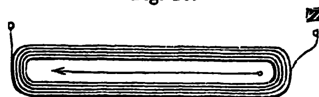
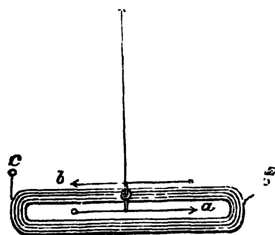


Fig. 47.



99. Rheoscopic instruments of this kind are especially sensitive, they detect readily the existence of infinitesimal current forces, from whatever source arising. Prideaux

* From the Greek ἄστᾰτος, "indifferent."

constructed a rheoscope of a pair of sewing needles, each three inches long; the rheophore or conducting wire consisted of four lengths of bell-wire, laid parallel and close to each other; it passed only once between the needles, and returned beneath the lower needle. The mere heat of the fingers, pressing on a pair of copper and tinned iron wires, deflected the needles 25 degrees.* This profound chemist also contrived other forms of rheophoric coils, consisting of bands of copper ribbon, about ⅝ths of an inch wide, with intervening paper between them, which proved extremely delicate; the magnetic needles being sensible of the least current force.

100. *Galvanoscope by M. Dubois Raymond.*—The latest, and perhaps the most delicate rheoscope, is the Galvanometer of Mons. Dubois Raymond, constructed with a view of detecting extremely weak electrical currents generated in the nerves and muscles of animals. M. Dubois Raymond has examined critically, and with great ability, the several circumstances liable to disturb the operation of very delicate instruments, and render them not only difficult to manage, but to a certain extent inaccurate. He first considers the liability of the compound or astatic needle (98) to deviate from the magnetic meridian, either from a want of parallelism in the needles, or defects in magnetising and suspension: in proportion as the two needles exactly compensate each other's force, and render the system insensible to the directive force of the earth; so the needles tend to a position of instability, and often rest out of the convoluted wires at right angles to the magnetic meridian. We may have also a cause of disturbance in the impurity of the metal constituting the rheophoric coil which may contain small particles of iron, or it may have acquired a tainted ferruginous surface in the process of drawing into wire through plates of steel. This last disturbing force was first observed by Nobili, who sought to obviate it by bringing a magnetic bar to

* See some extremely valuable Papers on Thermo-Electricity, by J. Prideaux. Phil. Mag., vol. iii., Third Series.

operate on the coil by induction, after the method practised by Barlow in neutralising the earth's force on the magnetic needle.* This method of neutralising the effects of magnetic disturbance in the rheoscope is not, however, altogether unexceptional. Dubois Raymond has sought, therefore, a more refined means: he makes the compensating magnet very small, and places it very near the end of one of the magnetic needles. It is, in fact, the mere broken extremity of a fine bead needle, and is so placed, that by means of small micrometer screws, minute changes may be made in its position. In this way the system is preserved accurately on the zero point, without any sensible loss of delicacy, since the small correcting magnet has little or no influence upon the needles beyond a deflection of a few degrees. This galvanoscope is mounted on a circular plate, carrying a graduated circle, and can be rotated on a central axis, so as to bring the coil into any given direction. The coil is a copper wire, 5584 yards in length, and about ·0055 inch in diameter; it is covered with varnished silk thread, so as to completely insulate the several convolutions. The wire is turned 24,160 times about a supporting frame an inch and three quarters in length in the clear and rather more than an inch and half wide. The needles are cylindrical; are each an inch and a half in length, and three hundredths of an inch in diameter. They weigh, taken together, four grains, and are connected by a thin piece of tortoise-shell.†

101. *Becquerel's Differential Rheoscope.*—This is a class of rheoscope, the object of which is to compare the relative force of two currents. With this view, two distinct rheophoric coils (97) are employed, identical in every respect both as to length, diameter, and material. The wires are coiled together about the same frame. The arrangement is perfect when equal currents traverse them in *opposite* directions without affecting the needles. When the currents are

* Rudiment. Magnetism, p. 152, sec. (164.)

† Abstract of Dubois Raymond's work, Dr. Bence Jones, F.R.S., p. 13.

unequal, the directions in which the needles deviate (77) indicates the stronger of the two. This instrument, by uniting the two coils, so as to allow the current to traverse them in succession in the same direction, is transformed into a rheoscope of a double length of wire, as compared with one of the coils alone; and when united, so as to cause them to operate together, it becomes a rheoscope, having virtually a coil of wire of an increased diameter, which, as compared with the single wire, will be as the $\sqrt{1} : \sqrt{2}$; that is, as 1 : 1·41. This instrument so far fulfils the purposes of four instruments; viz., a rheoscope of short coil, of long coil, of thick coil, and a differential rheoscope.

Very delicate rheoscopes have been constructed by Messrs. Nobili, Melloni, Ruhmkorff, and other philosophers engaged in this department of physics. They are all usually furnished with graduated circles for noting the angular deflections of the needles, and are carefully mounted on an appropriate base, on levelling screws, and covered with glass shades to protect the needles from currents of air.

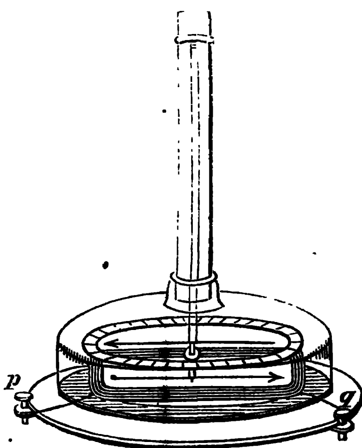
102. *Rheometers.*—Although the instruments just described are usually of excessive delicacy, and of great practical value in detecting small current forces, they are nevertheless defective as instruments of exact quantitative measure; and, notwithstanding that many attempts have been made, and Tables arranged with a view of determining the relations between the intensity and quantity of the current and the rheoscopic deflections, yet the results are by no means satisfactory. The kind of rheometer claiming the greatest confidence as a measure, is the simple rheophoric wire, (96), fig. 44, with a single needle. There is little reason to doubt but that the forces would be, in this case, as the tangents of the angles of deviation, or very nearly; or, taking the coil as a force deflecting the needle in a line perpendicular to the magnetic meridian, the force may be nearly measured by the sine of the angle of deviation.* The cards

* Rudimentary Magnetism, Part 2, pp. 121, 123.

of some rheoscopes have been graduated upon this principle, with a view of converting them into rheometers; for small deflections we may consider the angle of deviation as approximating to the force in operation, so that a deviation of four degrees may be taken as indicating twice the force of two degrees. The whole question, however, still remains in much uncertainty. All the elements of the rheoscope, affecting its conversion into a quantitative measure, have not been as yet fully considered when taken together; hence we have still much to investigate in the application of this instrument to the measurement of what may be termed quantity and intensity of the passing current.

103. *Bifilar Rheometer*, by the author.—This instrument, represented in the annexed fig. 48, consists of two needles, suspended by parallel silk fibres in the way already described (64) fig. 25. The needles are about seven inches in length. The rheophoric coil is a wire $\frac{1}{16}$th of an inch thick, about twenty-eight feet in length, and is turned eighteen times round the needles. The deflections are marked on a graduated circle by fine index wires at the extremity of the upper needle. The instrument is wonderfully sensitive. The magnetic system being nearly astatic, the forces will be measured by the reactive force of the parallel threads, and will be nearly as the angles of deflection,* or perhaps nearer

Fig. 48.

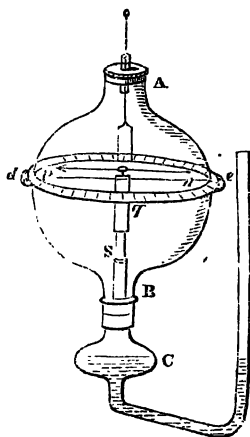


* Phil. Trans. for 1836, p. 417.

as the sines of the angles. The reactive force of a fine wire may be substituted for the parallel threads, as in Coulombe's balance. The connections with the battery are completed through the points *p*, *q*.

104. *Thermo-Rheophoric Electrometer*.—This may be considered as a species of compound rheometer; it was invented by the author, in 1836, for the purpose of comparing the heat evolved by the rheophoric, or current wire, with the magnetic deflections. It consists of a thermo-electrometer, such as already described (86) fig. 39, having a fine magnetic needle immediately over the wire, and a graduated circle placed around the ball to measure the deflections of the needle. The arrangement is represented in the adjoining fig. 49, which represents the ball of the instrument only: the remaining parts being as in fig. 39. The glass ball has openings above and below, at A and B, capped with brass, and closed air-tight by leather washers in the usual way: a small sliding tube S is joined to the screw cap which unites the ball with the cistern C, and carries a little open parallelogram of baked wood *q*, upon which the needle *n p* is poised immediately over the wire *d e*, passing through the ball. By raising or depressing the slide *s*, we may retain the needle near to, or distant from the wire. The needle is placed in position through the cap above, at A, and a small rod ending in a fork, covered with cotton thread, is passed by an air-tight collar through the centre of the cap, by which the oscillations or other disturbances of the needle may be mitigated. Supposing the ball with this apparatus substituted in the thermo-electrometer (fig. 39),

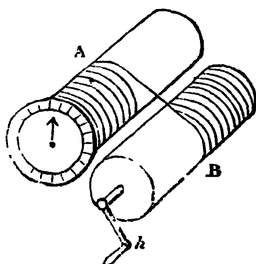
Fig. 49.



and a current transmitted through the wire, then we observe at the same instant the heating effect on the wire and the deflection of the needle, as shown by the thermometrical scale and the graduated circle, *d q e*, placed round the exterior of the glass ball. A small screw valve is placed in the glass, at right angles to *d e*, for regulating the air within the ball: it is not shown in the figure. The whole instrument is supported on a mahogany stand, on levelling screws, and is movable about a central pin, so as to bring the wire *d e* into the magnetic meridian.

105. *Rheostat.*—(97). We are indebted to Wheatsone for this valuable addition to our list of Voltaic apparatus. The object of the instrument is to measure the electromotive force and resistance in the rheophoric circuit, by means of variable instead of constant resistances. This is effected by interposing in the circuit variable lengths of wire, and thereby bringing the operation of different currents on the rheoscope to a ratio of equality, the electromotive force being inferred from the amount of resistance measured out in the length of interposed wire. In the annexed fig. 50, for example, let A B be cylindrical barrels, each of which may be turned round upon a longitudinal axis, one of them, A, being a non-conducting cylinder of baked wood, the other, B, a metallic cylinder. A brass wire of $\frac{1}{100}$th of an inch in diameter is coiled on the threads of a screw groove cut on the barrel A, and is finally continued on to the barrel B, so that by turning the handle *h* we may transfer as much of the wire as we please from barrel A to barrel B. If we now suppose the coils of wire, A B, to be introduced by adequate arrangements into a rheophoric circuit connected with a rheometer, it is clear that the current must traverse all the

Fig. 50.



coils on the wood cylinder A, but not all the coils on the brass cylinder B, because on the cylinder A they are all insulated in the wood thread, whereas on the brass cylinder B, they have complete metallic connection. We have, therefore, only to wind off or add as much increased resistance, measured by the length of wire on the barrel A, as is requisite, with different current-forces, to bring the rheometer to the same point of deflection, and then we obtain in these comparative resistances the relative force of the currents under examination. As the object of this contrivance is to regulate the circuit to a constant degree of force, it has, as already observed (97), been termed "Rheostat." The two barrels, A and B, are 6 inches long and 1½ inches in diameter. There is a scale to measure the number of coils wound or unwound. The threads of the screw on the wood barrel are forty to the inch, and the wire is thin and bad conducting, so as to obtain a greater amount of resistance in the circuit.

106. *Rheotome.*—(97). Several forms of this instrument for a continued interruption and renewal of the circuit have been contrived. The following simple arrangement will serve to convey a general and comprehensive idea of its nature and operation. If we give to a series of metallic radii fixed upon a central metallic axis a bad conducting circumference of baked wood or ivory, we shall then complete a wheel similar to the wheel of a coach, and if these metallic radii or spokes pass through the periphery, so as to be rather prominent, but fair upon its exterior surface, we have then a succession of interrupted conductors. Suppose now a metallic spring plate fixed on a rod of metal to press against the periphery of this wheel, and to be connected through its metallic support with the positive pole of the battery, and the axle of the wheel with the negative pole; then, if we turn the wheel round, the spring plate glides with friction upon the circumference over the terminations of the successive metallic spokes, and so continually breaks and renews the contacts with the battery.

A dentated metallic wheel with a spring plate has been sometimes employed in a similar way.

107. When a rapid interruption of the circuit is required, an automaton or self-acting rheotome is employed, consisting of a small piece of soft iron, attached to a metallic spring resting on a point connected with one pole of the battery. This piece of soft iron is placed within the influence of a soft iron bar or rod connected with the opposite pole, which is so circumstanced as to be temporarily magnetised by the passing current, on the principles explained in Chap. VII. When magnetised, it attracts the small contact iron, lifts the spring off the point, and thus breaks the circuit. The consequence is, that the magnetism induced in the iron bar vanishes at the instant, and the spring again falls back on the point; the contact with the battery is now renewed, and this alternation goes on with extreme rapidity.

108. *Rheotrope.*—(97). This instrument, for changing or reversing the direction of the current, has also a variety of forms. The object, however, in all of them is virtually to turn round the poles of the battery or reverse the order of the series; as this, however, would be difficult, and often impossible, experimentalists have sought to arrive at the same result by making a portion of the circuit moveable. A simple mechanical arrangement is as follows:—Let a small cylinder of baked wood be capped with brass, and mounted on a central axis on metallic supports in the way of an ordinary cylinder electrical machine; suppose two slips of metal to project, one from each cap, upon opposite sides of the wood cylinder, we have then two interrupted conductors in the direction of the circumference of the cylinder. Let two metallic springs on metallic bases be now adapted so as to press against opposite sides of the circumference of the cylinder, after the manner of the rubber of the electrical machine. Then supposing the metallic axes and caps to be connected with the opposite poles of the battery, and the two spring pieces at

the sides of the cylinder connected with the terminals of the circuit; we shall, on turning round the cylinder, so as to bring the metallic slips projecting from the caps in contact with the spring pieces, establish a current in a given direction from one terminal of the battery to one of the axle caps, and from thence through one of the spring pieces and through the circuit to the opposite spring piece, and from thence through the opposite axle cap to the other terminal of the battery. If now we turn the cylinder one-half further round, then all this is reversed; we first interrupt the circuit by the wood intervening between the slips of metal projecting from the cap pieces of the cylinder, and then again renew it in the opposite direction, by the contact of the spring pieces with the slips of metal in connection with the poles of the battery reverse to the former.

A simple rheotrope may be constructed of a non-conducting disc, moveable on a central point, and having two metallic slips crossing as chords of opposite quadrants. In moving this between two pairs of disjointed wires, one pair on each side, placed in connection with the terminal of the circuit and one of the poles of the battery, we complete the circuit through the metallic slips on the disc, either on one side or on the other, and so turn the current in either direction, the action is quite analogous to that of the four-way cock in the steam engine. Instruments of this kind have been frequently termed "commutators;" they are inseparable from the practical use of the electrical telegraph.

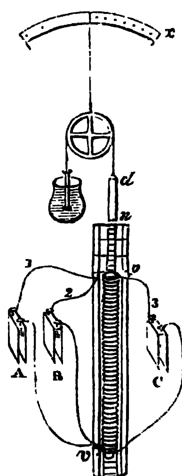
109. We have devoted some considerable space and attention to these rheoscopic instruments, because they are of vital consequence to the future progress of electrical discovery. The Electro-magnetic Multiplier (98) has unlimited application; it is, in fact, almost the only means at our command by which infinitesimal current force can be detected and its direction determined; such, for example, as extremely small current action in the muscular and nervous parts of animals.

It is therefore very important to perfect its construction to the last possible degree. The following are a few leading points to be kept in view. The rheophoric coil should be copper wire, as pure and as free from particles of iron as possible. The dimensions of the wire must depend on the conductability of the circuit In a circuit of low conductability, the coil should be long and fine, and the con volutions should be as near as possible to the needle. If the conductability be perfect, that is, involving a metallic circuit, it is better to employ a stout wire of moderate length. The wire in every case should be well covered with dry silk, and it may be nicely varnished, so as to insulate effectually the successive turns bearing against each other. The dimensions of the needles may vary in length from an inch and a half to three or more inches. In the delicate galvanometer of Nobili, to whom we owe the ingenious idea of the astatic needle, the needles are common sewing needles, about one and a half to two inches in length, magnetised to saturation, and placed about $\frac{6}{10}$ths of an inch apart. The copper wire is about the $\frac{1}{150}$th of an inch in diameter, closely covered with silk thread, is about seventy yards in length, and turned 800 times about the frame for the support of the coil. In another instrument the wire was about the $\frac{1}{50}$th of an inch in diameter, about 20 to 30 feet in length, and turned 70 times about the frame. A fine wire having 3000 turns on the multiplier has been in some instances employed, in others about thirty turns only of a thick wire has been used. As already observed (102), the electro-magnetic rheoscope cannot be implicitly relied on as an efficacious or exact quantitative instrument; the deflections of the needle not furnishing satisfactory comparative indications of the relative electro-motive forces, to which the deflections should be proportional: the liability of the magnetic needles to undergo change, the chances of an iron taint in the wire, and the introduction of variable resistances by the extent

of the coil, into the circuit, are all sources of difficulty; so that much still remains to be investigated before we can venture to place implicit confidence in the operation of this beautiful instrument as an exact quantitative measure.

110. Before concluding this branch of our subject, it may not be unimportant to call attention to another means of estimating current and rheomotive power taken as electrical quantity. This means is based on the development of magnetism of tension in soft iron. When a bar of soft iron is enveloped by an active rheophoric coil it becomes, as we shall presently see (210), powerfully magnetic; and the magnetic force developed will be, under given conditions, in some direct ratio of the current force and of the rheomotive power. The author has examined several of the relations of these respective elements, and has arrived at results calculated to throw further light on this important question.* Let *p v*, fig. 51, be a cylindrical rod of soft iron about 8 inches in length and half an inch in diameter, closely enveloped by three independent and distinct rheophoric coils, 1 2 3, wound round it together simultaneously, side by side; Let *n d* be a small cylinder of soft iron suspended from the wheel of the hydrostatic magnetometer, immediately over the iron rod,† the distance being measured by a divided scale *n p v*, to which the cylinder *p v* with its coils is fixed. Let A B C be three simple voltaic circles of Smee's or Daniell's construction (75) (79), having one of the coils, 1 2 3, appropriated to each, and with which they can

Fig. 51.



* Rudimentary Magnetism, Part 3, p. 63.

† For this instrument see Rudimentary Magnetism (126), Part 2, p. 111, fig. 76, frontispiece.

be connected at pleasure, and the rheomotive force of each of which is precisely the same. Let one of the systems A be first brought to operate on the iron cylinder *p v* through its appropriate coil 1, and let the reciprocal forces of attraction between the cylinder and the suspended iron be noted at a constant distance *p n*, as indicated on the arc *o x*. If now a second equal system B with coil 2 be added, the force will be quadrupled. If a third C and coil 3 be added, it will be nine times as great; that is to say, the reciprocal magnetic forces at a constant distance *p n* will be as the square of the increased rheomotive power, or as the square of the number of independent currents passing round the iron; so that to obtain the quantity of current force in action, or the rheomotive power, we must take the square roots of these attractive forces; and since we may infer, that if one current force produces one quantity of magnetism, then two equal and independent forces must produce *two* quantities, and so on; we may also conclude, that the reciprocal magnetic attractive forces are as the square of the quantity of magnetism—a law which the author has fully established for similar attractive electrical forces,* and with which the experiment is almost identical. It may be likewise further inferred, that current force and magnetic force mean much the same thing.

111. In these experiments we have supposed three equal rheometers and three equal coils distinct and independent of each other. When, however, we employ two coils and one rheomotive system only, say system A alone, with coils 1 and 2, then we have no longer this law of action; that is to say, the magnetic forces are no longer as the square of the number of currents; or if we employ two systems, A and B for example and one coil alone, say coil No. 1, then also the law changes—the reciprocal magnetic forces in the latter case will be in the direct ratio of the rheo-

* Phil. Trans. for 1834, p. 220, see (19), also Rud. Electricity, p. 131, see (112).

motive systems, so that the current and magnetic forces will be only in this case as 1 : 1·4 nearly, that is, as the square root of 1 to the square root of 2. Our limits do not permit of further pursuing this investigation here; but we think sufficient has been said to show, that a magnetic rheometer based upon this principle, fully worked out and applied, would be a valuable addition to our list of voltaic apparatus. Mr. Becquerel has done much towards this in the construction of an instrument termed by him "Balance Electrodynamique."

CHAPTER IV.

Electrical and Physiological effects of the Pile—Electrical Indications—Application of the terms "Tension" and "Intensity"—Law of Electrical Development throughout the series—The Tension dependent on the number of the alternations—Electrical effects separable from the chemical action—The Leyden Battery charged—De Luc's analysis of the Pile—Secondary Pile of Ritter—Physiological effects—The Shock—Effects on living Bodies—Powerful action of the Apparatus on Animals recently dead.

ELECTRICAL EFFECTS.

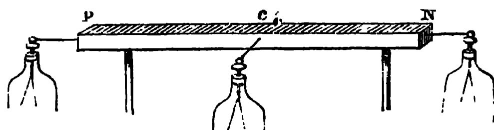
112. Volta, although he did not investigate to any great extent the electrical effects of his pile, and certainly not to any extent its chemical properties, had still satisfied himself of its action being similar to that of common electricity. The discoveries of the British chemists, however, very speedily showed that the pile was both an electrical and a chemical agent; that it was, in effect, what for distinction's sake may be termed both an electrical and a galvanic instrument; and it hence became a question of no small interest, how far its operation was purely electrical, and how far galvanic.

The first direct experiments relative to this question appear to have been instituted by Messrs. Nicholson and Carlisle, who in 1801 applied to it some of those delicate tests of electrical action already described (55). They found the silver extremity of a pile constructed with zinc and half-crown pieces in a negative, and the zinc extremity in a positive state of electricity. The following experiments may be quoted as being sufficiently illustrative of this question:—

Exp. 10. Construct a horizontal pile, of about 150 or 200 series, such as described (30) fig. 15, or a small long

Cruickshank battery (68) fig. 28, place it on insulating glass rods nicely varnished, as shown in the annexed fig. 52; then,

Fig. 52.



on applying the single gold leaf electroscope, (14) fig. 8, to either end of the pile, the leaf will be attracted, and will be subsequently repelled, as in the cases of ordinary electrical action. The electroscope described (61) fig. 23 is especially adapted to this experiment.

Exp. 11. The pile being insulated as before, apply the double leaf electroscope, (14) fig. 9, one to each extremity, and a third in the centre, as indicated in the above fig. 52. The electroscopes at the extremities of the series will be divergent, whilst the centre electroscope will not appear to be affected. If now examined by the usual tests,* the electroscope at the zinc extremity will be found positively charged, that at the copper extremity negatively charged. The single gold leaf electroscope, with electrical column or induction apparatus described (62) fig. 24, may be employed for detecting the opposite electrical states of the series; or weak charges of positive or negative electricity may be imparted to the electroscope, Exp. 10.

Exp. 12. Connect one of the extremities of the insulated pile, fig. 52, with the earth by a conducting wire, the leaves of the electroscope at that extremity will close; the leaves of the central electroscope will now open slightly, whilst the distant electroscope at the opposite extremity will diverge more freely.

Ritter found that when a communication was formed between the positive end of the voltaic pile and the earth,

* Rud. Elect. (14), p. 11.

the whole apparatus became negatively electrified, and when the communication was made with the negative end it became positively electrified.

113. As we are necessarily compelled, in treating this subject, to employ the terms "tension" and "intensity," as being of frequent occurrence in the sciences of electricity and magnetism, we especially desire to call attention to what we have already advanced on this subject in our Rudimentary Electricity, p. 141. sec. (120), more especially as some little misapprehension has occasionally arisen relative to such terms. By the term "tension" we are to understand—as its Latin derivation ("tendo") imports—a sort of straining or stretching of any kind, and by which a species of re-active force is called into being. Take, for example, the contractile force of an elongated elastic body, or conversely the expansive force of compressed air or a bent spring: in all these cases we have what is called a state of "tension," and the re-active force will be as the disturbing force directly. In the case of compressed air, for example, it will be as the compressing force; and consequently as the quantity of air or number of particles in a given space, that is, as the density. If we for a moment imagine the unknown cause of electricity to be a peculiar subtle elastic fluid capable of compression, then similarly twice the quantity upon a given area will have twice the re-active force; that is to say, its "tension" will be doubled. So that in this sense the "electrical tension" will be directly as the quantity of the accumulation on the same area. The same considerations would apply to any other assumption of the precise nature of the electrical agency capable of originating re-active force. Now the term "intensity" has a distinctive and rather different acceptation to this; it virtually signifies *degree* of *force*, or *degree* of *tension*. Thus the state of tension may be twice as great or intense in one case as in another.

114. In ordinary electricity this degree of tension,

that is, "intensity," is measured by the ordinary attractive or repulsive electrometers. When an instrument is used whose indications are strictly comparable, we find the *intensity* or attractive force of a charged system to be as the *square* of the charge directly. If, for example, twice the quantity of electricity be thrown upon a Leyden jar, the attractive force as indicated by an electrometer will be four times as great. Thus, whilst the tension is as the quantity simply, the intensity, taken as a measure, is as the square of the quantity, and the tension therefore as the square root of the intensity; the surface on which the electricity is collected being always the same: we may with propriety say "electricity of tension" or "tension of a charge," &c., but we cannot correctly say "electricity of intensity," or "intensity of charge," &c., although this last form of expression has been often employed conventionally, and "intensity" confounded with "tension," which should not be the case. According to the intensity electrometer, the tension of a charge would be four times as great with a double accumulation on the same area, whereas it is only twice as great, as we see by Lane's discharging electrometer, which shows the power of given accumulations to overcome distances or impediments in proportion to the quantity.

115. *Tension* also applies to the reactive force of particles constrained to assume a new condition or forced deviation from a normal state, as, for example, to the condition of the particles of a non-conducting medium, such as air under induction, between the opposed surfaces of a charged and neutral conductor.* Faraday has occasionally employed the term "tension" to designate electro-motive force; but as being expressive of any occult or specific quality of electricity considered as a material agency, no intelligible definition of the term has been as yet ever proposed. So far, the question is open to much further investigation. Until,

* For a full explanation of all these points, the student is referred to our Rudimentary Electricity, chap. iv. p. 141.

however, we become better acquainted with the nature and source of the agency we term electricity, and of which at present we may be said to be perfectly ignorant, it would be quite useless to speculate upon any occult or hypothetical quality it may be assumed to possess, under the designation of the term "tension."

116. It is impossible not to be struck with the great approximative condition of the pile to the similar existing conditions of a magnetic bar,* or that of an insulated charged conductor under the inductive action of a conductor either insulated or connected with the earth.† In the magnetic bar the system would appear to be too rigid to admit of the changes shown in Exp. 12, although the tendency is evidently the same, as is seen in connecting either extremity of the bar with a large mass of iron. In the case of the electrically charged and neutral conductor, many of the phenomena may be approximately, if not completely, obtained. Two electroscopes in connection, one with the positive, the other with the negative coatings of an insulated charged jar, are acted on in precisely the same way as the electroscopes at the extremities of the pile, Exp. 12. It would further appear from these experiments, that there is really what Volta terms an electromotive action through the pile, by which the zinc end becomes positive, and the copper negative, the electrical tension of either end being increased when the opposite extremity is connected with the ground. It is likewise further proved, that the interposed fluid has conducting, not insulating, properties. If the fluid were an insulator, these electrical changes could not occur. So far Volta's hypothesis applies very happily to the phenomena just enumerated Exp. 10, 11, 12, although it fails in a satisfactory explanation of the action of a simple circle; in this case we are obliged to assume the existence of a constant

* Rudimentary Magnetism (25), p. 21; (39) p. 35, part i.

† Rudimentary Electricity (20), p. 15.

circulation of the natural electricity of the elements by some unknown influence in the positive metal by which it attracts electricity from one body, at the same time it is giving it off to another (52).

117. The development of electricity of tension in the pile increases with the number of the series, and is also very dependent on the kind of fluid interposed between the plates. It may be readily conceived that in the insulated state of the battery (112) fig. 52, the first zinc plate can only act on the first copper plate; but the second zinc plate, receiving through the interposed fluid the accumulated charge of the first two plates, becomes more highly positive than if not so placed: to this accumulation we must add, as a constant quantity in the series, the independent action of the zinc plate on its associate copper, which renders it still more highly positive; hence, we have a sort of uniformly accelerating accumulation up to the terminating copper at the opposite extremity of the battery, and a final electrical tension proportional to the number of plates. This tension would be necessarily augmented by a metallic communication between the opposite extremity of the pile and the ground, Exp. 12, because such a communication would tend to increase the electrical capacity of the plate terminating that end of the series. On this principle, Mr. Singer found that in the contact experiment, (14) Exp. 6, the effect was considerably greater, when instead of insulating both plates, one of them was allowed to repose on the hand or some other conductor. This deduction, however, applies principally to the purely electrical developments of the pile, and has been found to obtain up to an arrangement in series of 1500 pairs of plates.

118. When two wires connected with opposite extremities of the pile are brought near each other, a small brilliant spark is observed to pass between them, which may, under ordinary circumstances, be considered as a purely electrical effect, and as a result of common disruptive discharge. The tension, however, is not sufficient to admit of any considerable

striking distance, as in the case of a spark from the common electrical machine. This voltaic spark, therefore, seldom exceeds a striking distance of more than $\frac{1}{30}$th of an inch; we may, however, with very active voltaic combinations, obtain a very rapid succession of sparks, which occur every time the contact with the battery is made or broken.

119. If, in completing the circuit, we make the contacts through a piece of well-burned charcoal, then the spark increases in brilliancy; and if taken between wires armed with charcoal points, the light, with a powerful battery, is of the most intense description, being almost insupportable by the eye. This astounding evolution of light does not appear to arise from any combustion of the charcoal, which, although partially ignited, suffers very little waste. The spark is brilliant in different gases; and will even take place when the charcoal points are immersed in fluids of low conducting power, such as oils and water. There is no doubt but that, in some cases, the production of the voltaic spark is mixed up with the ignition and combustion of the metallic surfaces between which it occurs.

120. In a highly rarefied medium, the spark taken between charcoal points may be extended into a beautiful arc of voltaic flame, of 6 inches in length, described by Sir H. Davy as resembling two cones with their bases opposite to each other, and producing beautiful coruscations of purple light. This effect may be also produced in air, with a very powerful battery, through a space of several inches. When the charcoal points, being heated to whiteness, are withdrawn from each other, then it is the voltaic discharge takes place through the intervening heated air.*

121. The electrical effects of the pile have been further found to depend materially upon the kind of fluid with which the metals are associated, and to be, as before observed (47), greatest when the chemical action of the series is least. Volta observed this in the electrical action

* Elements of Chemical Philosophy, p. 153.

of the "couronne des tasses" (32). Having charged the system with pure water, he observed the degree of divergence of his straw electrometer, and tried the power of the shock: On adding a small quantity of salt to each cup, the shock evidently increased, but the divergence of the electrometer remained the same. The most powerful *electrical* effects are produced by exciting an extensive series with common river water, by which a considerable charge is instantaneously imparted to the Leyden battery when connected with the extremities of the series.

Exp. 13. Construct a Cruickshank's trough (68) up to a series of 800 or 1000 plates, and connect the inner and outer coatings of about 10 square feet of coated glass with its positive and negative extremities. The coated glass will immediately become charged up to an intensity somewhat exceeding that of the voltaic tension, and will display through the ordinary electrometer active electrical development.

Exp. 14. Allow the Leyden battery to remain in contact with the extremities of the Voltaic series as before, and having connected the outer coating with a wire attached to the ball of a discharger, bring the ball near the knob of the battery. A rapid succession of sparks will be obtained by the continued charging and discharging of the jars; and if a fine iron wire be made the medium of discharge, and one end of it be brought to touch the knob of the electrical battery in a repeated succession of contacts, we shall obtain brilliant scintillations and sparks attended by a crackling noise. With the water batteries of Cross, Noad, and Gassiot, already alluded to (80), the electrical developments are exceedingly powerful: electrical attractions and repulsions occur freely; sparks, piercing electrical streams, and shocks are also obtained. Seventy-three feet of coated glass continues to charge so rapidly as to cause repeated and loud explosions. When discharged through gold-leaf, the leaf is brilliantly deflagrated. Fine iron wire is caused to scintillate; light substances are attracted by the charging ball of the

electrical battery at a distance of some inches, and repelled again.

122. The degree of electrical power thus developed will be, as just observed, in proportion to the extent of the series, or number of repetitions. The size of the plates appears to have but little influence on the results. Three or four hundred pairs of plates, of 2 inches square, well insulated and charged with water, are sufficient for common purposes; and it is important to observe, that this Voltaic battery has no such power, taken alone, as that which it gives rise to through the medium of coated glass. The most powerful electrical machine could not produce anything like such effects, although it could charge coated glass to a much higher intensity (113.) The quantity of electricity evolved by the Voltaic apparatus must be therefore necessarily very considerable, although very limited as to tension. It is, in fact, incapable of charging coated glass to any great elevation of the ordinary quadrant electrometer; but the degree to which it *can* charge it, is instantaneous. A single jar is always charged at once by the slightest possible contact, and to rather more than the intensity evinced by the extremities of the Voltaic battery employed.

123. It would appear, therefore, that the Voltaic apparatus can supply almost an unlimited quantity of electricity, but then its tension is comparatively weak, and there is little doubt but that much of the electricity developed by the metals is lost through the fluid conductor with which they are associated. When we interpose an electrical jar or battery between the poles or electrodes of the apparatus, we have a sort of magazine into which the electricity evolved is immediately received and stored up. The accumulation as to quantity, however, the intensity being limited, can only be in proportion to the extent of coated glass; hence we find that many equal jars, combined under the form of a battery, have greater electrical heating power than one jar alone,—a large jar greater than a small one; a small jar

greater than the apparatus itself. Now, the heating effects of common electricity being altogether independent of its intensity, as manifested by the common electrometers, and entirely dependent on the quantity, we should expect to find, as we do in this particular case, that the greater extent of surface we have in contact with the poles of the Voltaic apparatus, the greater will be the quantity of electricity accumulated and discharged at each breaking and completion of the Leyden circuit. We have, in fact, shown (Rudimentary Electricity, chap. vi.), that whatever be the extent of coated glass on which we accumulate a given quantity of electricity, or whether it be thick glass or thin, the whole quantity, at the instant of discharge, becomes concentrated, and will in any case produce the same effect on a metallic wire, although, if accumulated on a limited extent of surface, or on thick glass, the intensity as evinced by the ordinary electrometer may be very different.* The effect, therefore, being dependent on quantity, we can evidently, under a given degree of intensity, obtain a larger quantity of electricity upon a greater extent of surface than upon a small extent; and this is precisely the case now under consideration.

124. We owe to the ingenuity of the celebrated De Luc, as before remarked (47), a very masterly analysis of the Voltaic apparatus, in which he clearly shows that an important line of demarcation exists between the purely electrical and electro-chemical action of the pile, and the order of the series upon which each of these powers depends. He takes the three elements of the series, viz., the two metals and fluid in three different ways. He first places the fluid between the two metals; second, he joins the two metals together, first with the fluid in contact with one of them, and then in contact with the other, keeping the groups distinct by intermediate wire supports, so as to confine the action so far as possible to the respective groups.

* See Rudimentary Electricity, p. 163; also Phil. Trans. for 1834, p. 225. See also (189) p. 169, of this work.

The following figures, 53, 54, 55, represent these several arrangements.

In fig. 53 we have the fluid *f* between the two metals z s, with an intermediate wire support between each group. In

Fig. 53.

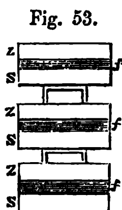


Fig. 54.

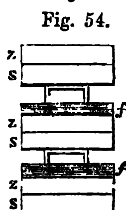


Fig. 55.

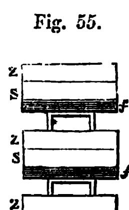
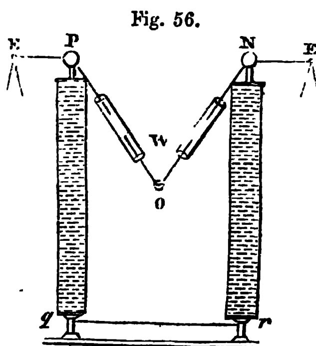


fig. 54 we have the two metals, s z, combined with the fluid *f*, in contact with the zinc z. In fig. 55 we have again the two metals, s z, combined with the fluid *f*, in contact with the silver s, the groups in each series being separated as before by an intermediate wire support.

125. This understood, we have to imagine an electrometer in connection with each extremity of the respective arrangements, and the opposite extremities further joined through an interrupted circuit of two wires in a tube of water, so that both the electrical and electro-chemical action of the respective groups may be observed: the one by the electrometers, the other by the decomposition of the water. The precise form of the experiment resorted to by M. De Luc is represented in the annexed figure, 56, in which P *q* *r* N represent two insulated piles connected at their zinc and copper extremities by a wire *q* *r*, so that P *q* *r* N may be considered as a single column, of which P is the positive, and N the negative extremity. Between these

Fig. 56.



extremities, P N, are two glass tubes, W, containing water, and disjointed wires connecting with each end, P N, of the column, and united at O. E E are two gold-leaf electroscopes, connected one with each end of the pile, as in Exp. 11 (112).

In this arrangement it may be perceived that the decomposition of the water between the extremities of the wires in the tubes W would denote the activity of the chemical action; they would be in fact two voltameters (93), whilst the electrometers E E would furnish a means of estimating the amount of pure electrical development. The piles employed by De Luc consisted of seventy-six pairs of zinc and silver plates, of rather more than an inch and a half in diameter; the fluid between being in some experiments pure water; in others, saline fluids.

126. The dissection of the pile excited by pure water, as indicated in fig. 53 (that is, with the fluid between the two metals), showed, that the extremity connected with the wire in the tube W, evolving oxygen, is positive, and that the current proceeds from this to the wire evolving hydrogen. With respect to the electrometers E E, they are not always both affected at the same time; sometimes one only diverges, either at the positive extremity P, or at the negative extremity N. The pile, when dissected in this way, acts electrically and chemically like the continuous pile, fig. 13 (27), but the action is less powerful. In either case, the shock from it is very insensible.

When dissected in the second way, as represented in fig. 54, with the wet cloth in contact with the zinc, the same electrical indications of the extremities P N are apparent; but the shock is insensible when the interrupted circuit is added; and no decomposition of the water is observable. Mons. De Luc concludes, therefore, that the electrical and chemical effects originate in different sources. Here is an instance of purely electrical action without chemical action.

The third dissection of the pile, in which the fluid medium

was in contact with the silver, gave neither electrical nor chemical indications.

In this set of experiments the interposed fluid was pure water.

127. When the intermediate cloth was saturated with a strong solution of muriate of soda, the first dissection of the pile, fig. 53, evinced similar electrical developments in every sense. Here, however, the power of the shock was considerable. When the interrupted circuit W was put on, the shock was less violent. Chemical action ensued, but was diminished by uniting the opposite poles, P, through each hand, thereby showing that the conducting powers of the human body are pretty nearly the same as water. Similar results to those before obtained followed in the cases of the second and third dissections of the pile (fig. 54 and 55).

128. M. De Luc concludes from these investigations that the electrical effects of the pile depend on the association together of the two metals separated in groups by a non-metallic conductor, whilst for the chemical effects we require ternary groups of two metals with a fluid between them. The pile, as dissected in the first way, fig. 53, is equivalent to the continuous pile, since we have the two metals connected by an intermediate wire frame. Here we have the arrangement requisite to the purely electrical effects, viz., the two metals separated by a fluid; and we have also the arrangement necessary to the chemical action, viz., two metals with a fluid between them. In the second dissection, fig. 54, however, we have not this latter grouping: there are the two metals in contact, and each group is separated by a fluid, hence the pure electrical action; but since there is no fluid actually between the metals, we have no attendant chemical action. The third dissection gives, as might be expected, neither result; first, because there is still no fluid between the metals, and, secondly, because the zinc has the copper plate on the one side and the wire-stand on the other; these counteract

each other, both having the same electrical relation to the zinc.

129. The different effects observable in these experiments led to a further examination of the relations between the chemical action and the oxidation of the zinc of the pile. With this view a comparative pile was constructed of the two metals, silver and pewter, the latter metal being but little oxidable by pure water, but very oxidable by muriatic acid: moreover it has a favourable electrical relation to the silver. The results of a careful series of experiments showed, that when the pewter was but slightly oxidated by the water, no chemical effects ensued, nor was there any shock perceptible, although the electrometers diverged freely,—the pewter extremity of the pile being positive, and the silver negative. When the pile was excited by a strong solution of marine salt, the electrical action evinced by the electrometers declined or ceased altogether. The shock, however, now became sensible, as also the chemical action in the interrupted circuit. On examining the state of the pile, the pewter plates were found oxidated. In any case of voltaic action, whether purely electrical or chemical, the current is retarded in its passage across the interrupted circuit.

130. The electrical effects of the pile we have been here examining are purely electrical, and may be termed primary effects, in contradistinction to certain other effects also electrical; termed secondary effects. Volta had observed, that when a slip of moistened paper is placed in connection with the poles of the pile, each half of it becomes differently electrified; that portion next the zinc, or positive extremity, is electrified positively, and that portion next the copper, or negative extremity, is electrified negatively. If this paper slip be now removed upon good insulating glass rods, this polar electrical condition of the paper slip remains for a short time. Ritter, struck by this fact, proceeded to construct a pile of alternations of moistened cloth with a single metal. The extremities of this series being placed in

conducting communication with the opposite extremities of the voltaic pile, it receives a charge similar to that of the moistened slip of paper,—one half of it becomes electrified positively, the other negatively. On breaking the connections with the voltaic poles, the electrical state impressed on the secondary pile remains, and it will continue to exhibit all the phenomena of the primary pile for some time. This kind of pile has been termed the secondary pile of Ritter.

Besides this class of secondary effects of the pile, there are other similar effects of an important and interesting kind, demanding especial attention; these, however, depending materially upon the condition of the metallic circuit joining the poles of the pile, and upon current and magnetic force, will be considered in a future part of our work.*

131. *Physiological Effects.*—By physiological effects we are to understand effects more especially connected with the functions or properties of animal life, or, in fact, with any species of animated organised matter.† We have seen, for example, that spasmodic and muscular contractions are elicited in the frog and other animals when exposed to the current of a simple voltaic circle (10), as also the peculiar sensations produced on the nerves of taste, in exposing the tongue and lips to the contact of two different metals (19). Such effects have been termed physiological effects, and they form a most important, and as bearing on the principle of vitality, a somewhat fearful scientific subject.

Of this class of effects, the peculiar sensation experienced by the animal frame, when uniting the opposite poles of the voltaic apparatus, demands especial attention. About forty pairs of plates, with an intermediate solution of marine salt, is sufficient to produce a shock sensibly felt in the hands and arms, when the opposite extremities of the pile are

* See (216), Chap. VII.

† Physiology—from the Greek of φύσις, "nature," and λόγος, "a discourse"—is the science of the structure of living beings.

touched at the same instant, one with each hand, the hands being well moistened with water. The most effectual way is to wet the hands, and hold in their grasp the bowl of a metallic spoon, we then bring the stems of the spoons to touch the opposite extremities of the pile. The character of this shock is less stunning, as it were, than that produced by the discharge of the Leyden jar, and less numbing than the shock of the Gymnotus and Torpedo; the precise sensation is scarcely to be described. By increasing the number of the series, this voltaic effect continues to increase in force, until at length it is perfectly insupportable. The acuteness of the shock does not, however, depend so much on the size of the plates of the series, as on the number of repetitions and the nature of the exciting fluid; a series of plates of three inches square excited with dilute muriatic acid, will produce a shock quite as acute, although perhaps not quite as dense, as the same number of plates of six inches square. When excited, however, by river water, the shock of the same battery is scarcely perceptible.

132. The great discovery of the voltaic pile, and its subsequent conversion by Cruickshanks into a form of apparatus of increased power, necessarily led to very extensive experiments in its application to the resuscitation of suspended life, or to the semi-restoration of animal functions in cases of recent death, all of which involved physiological questions of deep and intense interest.

A very moderate battery is sufficient to produce muscular motion in animals recently dead. If a wire, proceeding from the copper end of a Cruickshanks's trough, containing about 100 pairs of plates (68), and excited by dilute acid, be put into one of the ears of an ox or a sheep just killed, and another wire be introduced into the opposite ear, then, at each completion of the circuit with the zinc extremities of the battery, at small intervals of time, strong convulsive movements and contractions ensue in the several muscles about the head and face, and which go at

first very far in impressing the experimenter with the idea, that all the original sensient powers are restored. The eye-balls become so affected as to roll apparently in their sockets, the eye-lids open and close, and a sort of smelling and chewing motion is excited in the muscles of the mouth and face, during which the nostrils vibrate freely and the jaws appear to masticate. When a horse, soon after it has been shot, is exposed to the electromotive action of the apparatus, the limbs struggle with so much power as to require the united force of many persons to restrain them. In the course of some experiments of this kind on the head of an ox recently killed, the tongue was so forcibly drawn into the mouth as to detach a strong skewer by which it was secured to the table.* The legs of a frog also, with a much less powerful battery, may be caused to leap to a considerable distance.

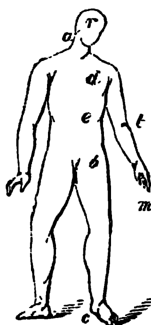
133. Of this class of experiment the application of the voltaic current to the human frame, either in a state of perfect life or immediately after death, must be regarded as the most exciting and perhaps the most important; although in many cases awfully painful to behold. If a limb recently amputated be exposed to the action of forty or fifty pairs of plates, the muscles are immediately thrown into convulsive and contractile motion, whilst a powerful battery excites in a recently executed criminal, terrible efforts of spasmodic life. The first experiments of this kind appear to have been made at Turin, on criminals who had perished by the guillotine. The most complete experiments, however, on record, are those carried out at Glasgow by Dr. Andrew Ure, 4th November, 1818, on the body of a recently executed criminal, a man of middle stature, about thirty years of age, athletic and muscular. The body had remained suspended for nearly an hour, no convulsive motion was apparent at the moment of execution. The body was

* Wilkinson's Galvanism, vol. ii.

brought to the University about ten minutes after having been removed from the gibbet. What renders these terrible experiments the more valuable is the great philosophical circumspection and care with which they were conducted; all the dissections having been carefully made under the immediate superintendence of the Professor of Anatomy, Dr. Jeffrys. The battery consisted of 270 pairs of four-inch plates, charged with dilute nitro-sulphuric acid (68). Under these circumstances the following experiments were carried out; the annexed diagram, fig. 57, being taken to represent the general contour of the body.

134. 1°. An incision was made at *a*, right under the occiput at the top of the spine, and the spinal marrow exposed. Another incision was made at *b* at the left hip, and the great sciatic nerve passing there laid bare. Finally, a third incision was made at *c* at the heel. Connections being established through *a* and *b* with the zinc and copper extremities of the battery, all the muscles of the body became violently agitated by a sort of convulsive shivering, more especially on the left side. On removing the wire at *b*, to the heel at *c*, the knee, which had been previously bent, was thrown forward with such force as to overturn those who tried to restrain it.

Fig. 57.



2°. An incision was now made at *d*, about three inches above the clavicle, so as to expose the nerve there connected with the principal muscle of respiration, the diaphragm, and communicating also with the heart. Another incision was made about *e*, under the cartilage of the seventh rib, close to the diaphragm. On making the contact with the battery very perfect between these points *d e*, and at the same time drawing the distant extremity of one of the connecting wires of the battery rapidly over the plates in

the last trough leading to either of the electrodes or poles, laborious breathing instantly commenced; the chest began to heave, and all the auxiliary machinery of respiration were called into operation. This experiment appears to have been the most striking experiment as yet made with the voltaic apparatus; and although no pulsation could be detected at the wrist, owing to the blood-vessels having been so long drained of blood, yet it was inferred, that but for this evacuation, that phenomenon might also have been produced.

3°. An incision was now made at *r*, just above the eyebrow, so as to expose the nerve which passes out there, and connections with the battery made with the heel at *c*. On running one of the wires over the plates as before, from the 220th to the 270th pair of plates, thereby accumulating a rapid succession of 50 shocks, each greater than the preceding, every muscle of the face became thrown into a state of fearful action, expressive of rage, horror, despair, and eliciting such ghastly smiles as to drive several of the spectators from the apartment.

4°. The last experiment consisted in transmitting the voltaic current from the connection with the spinal marrow at *a* to the great nerve of the arm, where it passes by the elbow at *t*. The fingers now moved with great rapidity and flexibility like those of a performer on the violin. On removing the connection from *t* to an incision in the top of the forefinger at *m*, the finger instantly became extended, and in such way as to appear to point to different persons.

135. From the amazing influence of the voltaic apparatus on these apparently extinct vital functions, it is difficult to say, as observed by Dr. Ure, whether life might not have been eventually restored, supposing the exciting current had been at once applied to the muscles of respiration between *d* and *e* before the spinal marrow had been wounded, and the blood-vessels exhausted of their blood; Dr. Wilson Philip having shown that the action of the diaphragm and

lungs must precede the restoration of the circulation and the action of the heart: the conclusion is an important one, inasmuch as it indicates an effective application of the apparatus in cases of suspended animation from noxious vapours or other causes. In such cases Dr. Ure proposes as the most hopeful course, to transmit the current along the channel of the nerves, thereby providing a temporary substitute for that nervous influence, without the presence of which life is impossible. It would appear from Dr. Wilson Philip's very beautiful physiological experiments, that the metallic electricity of Volta, can really stand for or supply the place of what has been termed the nervous fluid. Having destroyed the nerves of digestion in some rabbits, he succeeded in carrying on the functions of the stomach by means of the voltaic current, and so as to sustain life and digestion during a period of 26 hours. His general conclusions are, that voltaic electricity can effect the secretion of fluids from the blood requisite to the purposes of animal life, and that, too, much in the same way as is effected by the nervous power,—a conclusion which has been further verified by other physiologists.

136. A vast number of experiments made upon recently executed criminals and large animals, show that what has been termed galvanism exercises a powerful stimulating action on the muscular and nervous systems; that the stimulation is far greater than anything resulting from any mechanical agency, and is hence a powerful means of restoring suspended life, combined with other remedies, in severe cases of asphyxia, arising from any cause; but the actual vital primary power it can never supply.

CHAPTER V.

CHEMICAL EFFECTS OF THE PILE.

Brief Review of the nature and objects of Chemical Science—Elements of the Material World—Doctrine of Definite Proportions—Acid and alkaline effects of the opposite Electrodes in changing the colour of Vegetable Infusions—Revival of Metals—Decomposition and Recomposition of Water—Grotthus's Theory of the Transfer of Elements—Davy's Researches and Experiments—Decomposition of the Alkalies—Further Illustrations of the Electro-Chemical action of the Pile—Review of the Theories of Davy and Faraday.

137. Before entering upon this branch of our subject, it may not be undesirable to advert briefly to the nature and objects of the science we term Chemistry, as being essential to a full appreciation of the voltaic apparatus considered as a chemical agent. We may here observe, as common experience teaches us, that the various bodies around us and of which the material world is made up, are in a constant state of change to a greater or less extent. We see water, for example, assuming the form of vapour. What is called the decay of the leaves and branches of trees exposed to the winds, rain, and other atmospheric influences, is in fact the conversion or transmutation of one kind of substance into another. We observe in our common fires the beautiful phenomenon of combustion, this is in fact nothing more than a new combination of the constituents of the fuel with a portion of the air we breathe. In the union of an acid with an alkaline substance, such, for example, as that of nitric acid, vulgarly called aquafortis, with potassa, commonly called potash, we observe two acrid caustic bodies, each in itself pungent and destructive, so combined as to lose all their primitive characters and constitute a mild neutral salt termed the nitrate of potassa, vulgarly called

saltpetre. Now, in all these processes not a particle of matter is lost; all is change only, either of form or conversion; —one kind of substance, in fact, is converted into another kind. Now, it is the object of chemical philosophy to trace and examine the nature of these changes, to determine as far as possible the simple elementary constituents of every kind of substance, that is, the primary matter of which various bodies consist, and to investigate the great natural agencies or powers by which these chemical combinations are established or subverted. The term Chemistry, in fact, really signifies a knowledge of the constitution of the various bodies composing the material world;* and the powers by which they are regulated and controlled.

138. Although the several kinds and forms of matter around us are almost innumerable, and the changes of which they are susceptible almost infinite, still the analytical eye of chemical science, perceives amidst what may seem to be a confused variety, about fifty-two distinct elementary bodies; out of the various combinations of which, in quantity and proportion, all other substances arise. These bodies have been termed simple elements; they are considered, however, as elements, only so far as they are by any means in our power incapable of further change, or of being resolved into other kinds of matter; they are all subjects of weight and measure. Of these elements four have especial and marked powers, as displaying an extraordinary disposition to unite with the remaining forty-eight, and which they act upon in various ways—corroding, penetrating, or dissolving them. These four bodies have been termed oxygen, chlorine, iodine, and fluorine. The remaining forty-eight elements consist of:—1°. Two gaseous bodies, termed

* The term "Chemistry" appears to have been originally taken from the Arabic of "Kimia," which signifies occult, or concealed, and was preceded by the term "Alchymy;" a term given to a sort of tentative, or speculative, process for converting the baser metals into gold: a term, also, from the Arabic of "al," the, and "kimia," secret, from "kamai," to hide.

hydrogen and nitrogen. 2°. Two fixed infusible solids, termed carbon and boron. 3°. Two fusible volatile solids, termed sulphur and phosphorus; and forty-two metallic bodies, such as gold, silver, copper, &c.

139. The great unknown powers of nature to which these elements of the material world are subject, and by which their combinations under various forms of substances are established or subverted were, up to a late period, but very indistinctly apprehended. An hypothetical force, termed chemical *attraction*, chemical *affinity*, or elective *attraction*, was the supposed cause or causes of these various changes in the elements of matter. Geoffroy, an acute French physician, says: "There are certain relations amongst the different bodies which cause them to unite," that "those which unite by preference have the greatest affinity," that is, the greatest attraction for each other. Take, for example, the decomposition of a solution of the carbonate of soda of the shops by tartaric acid. In this case, on adding the tartaric acid, the soda immediately combines with it, and its union with the carbonic acid is at an end, which hence becomes, as it were, thrown out as fixed air. Similarly, if we mix solutions of nitrate of baryta and sulphate of soda together in certain proportions, the acids in these salts will actually change places, the nitric acid, in combination with the baryta, will go over to the soda, and the sulphuric acid, in combination with the soda, will go to the baryta, and we shall have the two original salts converted into two new salts by this sort of elective attraction; (viz.), sulphate of baryta, which is insoluble in water, and which sinks to the bottom of the vessel, and nitrate of soda, which remains in solution.

140. Bergman, and subsequent chemists, modified and adopted these views, which were generally received. At length, a vast number of beautiful experimental inquiries led to a larger and more comprehensive idea of chemical combination. Dalton, a name illustrious in the annals of chemical philosophy, propounded, about the year 1803, a

theory of chemical combinations of singular interest. Having assumed that matter is made up of infinitely small particles, termed "atoms," he deduced a law of combination of these atoms in definite or limited proportions. Thus, for example, 40 parts of sulphuric acid combine with 77 parts of baryta, to produce 117 parts of the insoluble salt termed sulphate of baryta, and no way of putting these substances together in quantity can affect these definite proportions. Dalton also supposes, that in chemical combinations, one atom of one constituent always unites, either with one atom of another constituent, or with two atoms, or with three, and so on in multiples; each combination, although a combination of the same elements, forming a different substance. Thus the chemical constituents of the air we breathe are really those of the caustic destructive substance we term aquafortis, or nitric acid; but then the constituents are combined in different proportions. Dalton further imagined, that the *relative* weights of these ultimate material atoms might be inferred from the proportions in which the two constituents unite. Such relative weights he termed *atomic* weights. Although the assumption of material atoms is evidently a piece of pure hypothesis, yet, as a sort of scaling-ladder to higher chemical knowledge, it is a convenient hypothesis. Wollaston, however, in order to express the definite proportions in which substances combine chemically, uses the less objectionable term, "chemical equivalent." Davy, on similar grounds, employs the term "proportion" only. The term chemical equivalent then implies the proportion of a given substance, requisite to act by the laws of chemical affinity on another substance, to form a new substance. The result of all this has been a table of equivalent numbers for each element of a compound, expressing the ratio of combination reduced to its lowest terms; the number for a given prominent element, say hydrogen, being taken as unity. Let, for example, the relative equivalents, or atomic weights, of the following substances be; hydrogen

= 1, carbon = 6·12, oxygen = 8; then whenever hydrogen and carbon combine chemically *particle to particle*, they will unite by weight in the ratio of 1 : 6·12; similarly, 8 of oxygen will unite with 1 of hydrogen, or 6·12 of carbon.

141. The profound French chemist Gay Lusac, and the celebrated Humboldt, following up Dalton's views of chemical union according to definite proportions, made a further discovery of a similar law for gaseous combinations. They showed that in the combination of gases, these substances unite by volume also in simple definite proportion. Thus they observed, that water for example, is formed out of the union of 100 volumes or measures of oxygen, and 200 of hydrogen, and of no other relative quantities; which would be the ratio of 1 : 2, combinations of 1 : 1, 1 : 2, 1 : 3 as measures of volume they found to obtain in all gaseous combinations.

142. It would be trespassing too much on the limits of this work to pursue these brief remarks further; we have said enough, perhaps, to render intelligible the bearing of voltaic electricity on the science of chemistry, under the form of a new science, termed Electro-Chemistry; and to show how wide a field of chemical research became exposed to view by the discovery of such an astonishing agency as that of the voltaic current (23) (33), exerting as it does, an influence almost omnipotent over the constituent elements of bodies. Hitherto the agencies at the command of the chemist were principally the action of substances on each other; that is to say, chemical affinity, and that of caloric or fire. Here, however, we have a new power greater than any thing the imagination of the chemist could have devised.

143. The beautiful discovery of the decomposition of water through the agency of the voltaic battery (35), may be considered as the great fundamental experiment of what has since been termed Electro-Chemistry. Messrs. Nicholson and Carlisle not only effected the evolution of the constituents of water from the wires in connection with the

opposite extremities of the pile, but they further collected the two gases, hydrogen and oxygen, in separate tubes, and found the comparative volumes, evolved in the same time, to be in the same proportions as those in which, by their chemical combination, they would again re-combine into water (141). By means of his improved battery (68), Cruickshanks very fully confirmed these results, and made still further advances in the new science of electro-chemistry (36): he employed silver wires in the water of the interrupted circuit (35), and coloured the water slightly with tincture of litmus. Then it was observed, that the silver wire coming from the zinc extremity of the battery, turned the colour of the fluid in contact with it faintly red. On colouring the water with a weak infusion of Brazil wood, the silver wire coming from the copper extremity of the battery changed the colour of the fluid around it to a deeper shade, inclining to purple. Now, as these effects are precisely the same as those resulting from the addition of an acid or an alkali to water so coloured with litmus or Brazil wood, it was inferred that an acid had been generated at the point of the silver wire coming from the zinc or positive extremity of the battery, and an alkali from the silver wire coming from the copper or negative extremity of the battery.

144. When the voltaic current was passed through the same interrupted circuit, in a glass tube filled with solution of acetate of lead, commonly termed sugar of lead, the lead was observed to come out of the solution of the metallic salt, and collect upon the extremity of the negative wire. Other metals became similarly revived from solutions of metallic salts, such, for example, as silver from solution of nitrate of silver, copper from solution of sulphate of copper, &c. Various neutral salts, in solution, as the sulphate of soda, &c., were also decomposed in a similar way, and resolved into their constituent elements—an alkali and an acid.

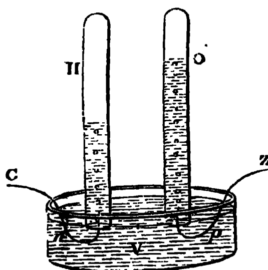
145. By a careful investigation of the gases collected, the

effects of wires of different metals, and the influence of the fluid in the interrupted circuit, Mr. Cruickshanks further concluded; that in any fluid containing water, the gas evolved by the wire coming from the copper extremity of the battery is always hydrogen; and if the fluid in the interrupted circuit be a solution of some metallic salt, then the metal of that salt is caused to re-appear, as it were, out of that solution, upon this same negative wire. If the wire coming from the zinc extremity of the battery be a wire of platinum or gold, which metals are not liable to oxidate, then pure oxygen is always disengaged from this positive wire; but if the wire be a wire of copper, or other metal liable to oxidation, then this positive wire becomes covered with metallic oxide, and but little oxygen is evolved. He also found that fluids not containing oxygen *will not* transmit the voltaic current, but that any fluid which does contain oxygen *will* transmit the current.

146. The following experiments will be found highly instructive illustrations of these electro-chemical effects of the voltaic apparatus.

Exp. 15. Fill two small glass receivers, H O, fig. 58, of about $\frac{3}{4}$ inch in diameter, with water, and invert them in the usual way in a vessel, V, also full of water. Let two wires *p n* of gold or platinum be attached as terminations to the copper wires Z C to be connected with the opposite extremities of the voltaic battery. Then, immediately the circuit is complete, bubbles of gas will continue to be evolved from each of the wires *p n*, which will rise up and displace the fluid in the small receivers H O, and in such way that twice the volume of gas will be disengaged from the negative wire C *n* in a given time, as is disengaged from

Fig. 58.



the positive wire *p* z; so that if the two receivers H O be precisely equal, then, when all the water is displaced from the tube H over the negative wire *n*, only half the water will have been displaced from the tube O over the positive wire *p*, thereby showing that the comparative volumes of the evolved gases are as 1 : 2. (141.)

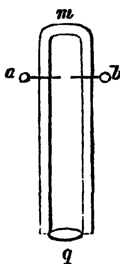
Exp. 16. Remove the receiver H, whilst carefully retaining the gas within, and after reverting it, apply a lighted taper to the mouth of the tube; the gas may thus be inflamed. Remove the receiver O in a similar way, and apply a lighted taper as before; the gas in this tube will not inflame, but if a small lighted match be immersed in it, the match will burn with great brilliancy.

It will be immediately perceived, from these effects, that the two gases display the great properties of hydrogen and oxygen gases, according to ordinary chemical tests.

Exp. 17. Fill one of the receivers O as before with water, and having inverted it, bring both the wires *p n*, fig. 58, immediately under it, so that the two gases evolved may rise together into the same tube, and displace the water. When full of the two gases, remove the receiver, revert it, and apply a lighted match to the mouth of the tube. The gases will then explode and vanish into water.

A very elegant form of this experiment is shown in the annexed fig. 59, in which *m q* is a very thick and strong tube of glass, about $\frac{3}{4}$ths of an inch interior diameter, and 10 inches long, having two short wires *a b* secured through holes pierced in its sides immediately opposite each other, leaving a small interruption between them within the tube. Having collected the gases as in the last experiment in this thick tube or receiver, secure it by a cork thrust into the lower orifice *q*. If now an electric spark from a small Leyden jar be passed through the interrupted wires *a b*, the two gases will recombine into water with explosive

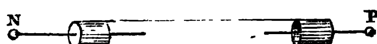
Fig. 59.



force, and the cork *q* will be driven with violence out of the mouth of the tube.

Exp. 18. Fill a glass tube of about half an inch or more in diameter with dilute solution of the muriate of tin, the solution being secured in the tube by a cork fitted in each end of it. Let a metallic wire be passed through the centre of each cork, and project freely within the tube, as represented in the annexed fig. 60. Connect one of the wires P

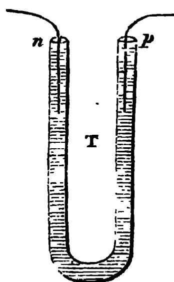
Fig. 60.



with the positive or zinc pole of the voltaic apparatus, and the other wire N with the copper or negative pole. Then will an extremely beautiful vegetation of metallic tin begin to grow around the negative wire N, and will soon cover it. A similar result ensues in solutions of other metallic salts.

Exp. 19. Fill a syphon tube, T fig. 61, of about half an inch in diameter, with a delicate infusion of red cabbage leaves, and introduce into each side of it a platinum wire as indicated in the figure. Connect the wire *n* with the *negative* side of the voltaic apparatus, and the opposite wire *p* with the *positive* side; after a short time the infusion on the positive side *p* will have changed to red, and that on the negative side *n* to green. If the connections with the battery be reversed, that is, if *n* be connected with the positive side, and *p* with the negative, then the colours will gradually subside and change places, the side *n* will turn to red and the side *p* to green, thereby showing that an alkali has been determined to the negative wire, and an acid to the positive, the same results being obtainable by the addition of a weak alkaline or acid solution to either leg of the tube,

Fig. 61.



and of which this vegetable infusion is in its change of colour a most delicate test.*

147. On reviewing these early results of voltaic action, we cannot but be impressed with the singular and wonderful influence of the apparatus as a chemical agent, and its powerful sway over the particles of common matter; such results alone would necessarily awaken in a philosophical mind the most intense interest, but the progress of the new science of electro-chemistry was destined to elicit still greater effects, and lead to questions of still deeper interest. Ritter, a young and ardent experimental philosopher at Jena, observed, that in the decomposition of water (146), Exp. 15, it was not requisite to terminate the wires of the battery in the *same* vessel, but that portions of water separated by sulphuric acid still underwent decomposition when connected with the positive and negative extremities of the apparatus, oxygen being still evolved from the positive wire, and hydrogen from the negative. Now, one of the effects observable in the original experiment of Nicholson and Carlisle (35), considered at the time as surprising, and difficult of explanation, is the production of the separated elements of water at the opposite electrodes (42) of the apparatus, and that too without any discoverable transfer of either of the disengaged elements. We will imagine, for example, a particle of water decomposed at the positive electrode, say at *p* fig. 58 (146), then the hydrogen from which the oxygen is separated and evolved must be supposed to travel to the negative electrode *n*, and to be only apparent on reaching that point. Conversely, if we suppose the decomposition to be at the negative electrode, then we must conceive the separated oxygen to travel to the positive electrode. All

* To prepare the test:—We infuse the minced leaves of the red cabbage in a small quantity of distilled hot water, and then strain off the liquid, which will have a delicate blue colour, and will become green by the least addition of an alkaline solution, and red, by adding the weakest acid solution.

this becomes the more wonderful in the experiment of Ritter, in which the elements must be imagined to travel through intermediate acid. This appeared to Ritter so unlikely, that he was led to imagine that the particles of water at each pole were wholly transformed, one into oxygen, the other into hydrogen.

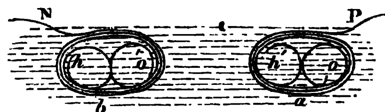
148. Davy, whose future electro-chemical researches were destined to shed so much lustre on British science, struck by this extraordinary experiment, submitted separated portions of water placed in different glass vessels to the influence of the voltaic apparatus, as indicated in fig. 64 (151); no result ensued so long as the two portions of water remained disunited; directly, however, they were joined by a conducting wire or other channel of conduction, then the decomposition went on in each glass as usual. In this experiment, if any transfer of either of the elements of water took place, it must have been necessarily through the intermediate communicating wire or other conductor.

149. Grotthus examined this question with great ability and ingenuity. He supposes, in the chemical constitution of water, an atom of hydrogen to be united to an atom of oxygen; * that these substances have certain natural electrical tendencies or conditions, hydrogen being a positive body, and oxygen a negative body (17). Whilst constituting water, these natural electricities neutralise each other, and hold the two atoms together, the two forces being then in equilibrio. Directly, however, a particle of water is exposed to the influence of the voltaic series, this equilibrium is overset or disturbed, and a particle *a*, fig. 62, at the positive extremity P will have its oxygen atom *o* drawn towards P, and its hydrogen atom *h'* repelled from it. The one (oxygen) being by the hypothesis an electro-negative

* Dalton supposes one volume of oxygen to contain as many atoms as two volumes of hydrogen; so that, although we suppose the gases united atom to atom, still, taken as volumes, they are united in the proportions of 1 : 2.

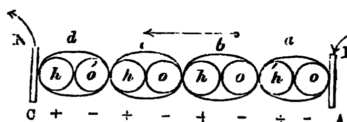
substance, and the other (hydrogen) an electro-positive substance. Conversely, a particle of water *b* at the negative

Fig. 62.



extremity N of the apparatus, will have its hydrogen atom *h* drawn towards N, and its oxygen atom *o'* repelled from it.* The two elements of the water will be so far loosened in their state of chemical union. A similar result will ensue in the next succeeding particle of water by the influence of the atoms *h' o'*, and so on through all the intermediate conducting chain between *a* and *b*; that is to say, we shall have what has been termed a polar electrical series, in which all the positive electricities look one way, and all the negative electricities the other,† as indicated by the positive and negative signs in the next fig. 63, in which A P represents

Fig. 63.



the anode, or positive electrode; C N the cathode, or negative electrode (39); *a b c d* being successive particles of water made up of the gases oxygen and hydrogen *o h*, and in opposite electrical states, as denoted by the signs + and —.

150. The atom of oxygen *o*, particle *a*, fig. 63, being as it were thus loosened in its combination with the hydrogen atom *h'*, the positive wire P, by neutralising its negative

* Rudimentary Electricity (16), p. 13. "Similar electricities repulse, and opposite electricities attract each other."

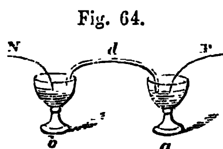
† Ibid (38), p. 45.

electrical energy, may either combine with it, or set it free altogether under the form of gas. Similarly, the negative wire N may set free the hydrogen *h*. Directly, however, the first oxygen atom *o* is evolved, and its associate hydrogen *h'* left alone, then this same hydrogen *h'* effects a decomposition of the next particle of water *b*, unites with its oxygen atom, and again forming water, sets the next hydrogen atom free; and so on through the whole chain of electrical action, up to the last particle of water *d*, at the negative wire N, where an atom of hydrogen *h* is finally dismissed altogether in yielding up its positive electricity to the negative wire. We may easily conceive a series of decompositions and recompositions converse to this, from N towards P, thereby causing a mutual interchange of opposite electricities and a final evolution of the two gases at the opposite wires P N by the continued action upon successive particles of water in contact with them. A mechanical illustration of this sort of action may be derived from the impulse upon a series of suspended elastic balls (24), fig. 11, a comparison by Grotthus himself in further elucidation of his theory, and which very plausibly removes the difficulty in explaining the evolution of the gases from the positive and negative wires of the apparatus, when separated by a considerable interval or placed in distinct vessels of water united by conducting matter (147) (148).

151. The preliminary experiments by Davy (148), carried on between the years 1800 and 1805, were soon followed by a far wider range of experimented investigation, giving rise to the most brilliant results and discoveries which had as yet adorned this department of science. It was evidently to be inferred from the phenomena developed (146) in experiment 19, that alkaline matter is evolved at the negative wire *n*, fig. 61, and acid at the positive wire *p*; and it would hence appear that an acid is generated by the positive wire, and alkali by the negative wire. Such was not, however, Davy's

view of this result. He conceived that the alkaline and acid matter arose from the action of some peculiar power of the apparatus, by which hydrogen and inflammable matter, alkalies and metals, are determined to its negative pole, and oxygen and acids to its positive pole (37); that the forces thus excited are sufficiently powerful to detach the substances in question from their most intimate combinations, and that hence the alkaline matter found in the water arose from a partial decomposition of the matter of the vessels used in the experiment, and the acid from the oxygen of the water with the nitrogen of the air. Davy, in the years 1806 and 1807, with consummate skill and address, fully pursued this momentous question through all its various and perplexing phases. Instead of a continuous vessel or syphon tube, employed in Exp. 19, fig. 61 (146), he had recourse to separate vessels, and in order to avoid all possible interference from disturbing causes, he employed vessels of agate filled with water, carefully distilled, and connected by fibres of transparent amianthus or mountain flax. The arrangement is represented in the adjoining fig. 64, in which P N are the wires attached to the positive and negative extremities of the apparatus having terminations of gold or platinum; *a*, *b* the agate cups, containing distilled water, and *d* the fibres of amianthus connecting them. The result, however, was still traces of acid at the positive wire P, and alkali at the negative wire N, notwithstanding the great precautions resorted to. When, however, instead of agate vessels glass cups were employed, the alkaline traces became much more marked and abundant, which should not have been the case, if the matter of the vessel containing the water had no influence on the result. Davy, therefore, still inferred that the source of the alkali was to be sought for in the decomposition of the matter of the vessel employed in the experiment.

Fig. 64.



Under this conviction, and to completely avoid this source of fallacy, two cups, *a*, *b*, fig. 64, of pure gold, were now employed, containing water distilled from a silver still, these gold cups being connected with the incombustible mineral fibres as before. Still further to perfect the experiment, the whole process was conducted under an exhausted receiver, from which all traces of oxygen were removed, so far as possible. In this case, the result was in complete accordance with Davy's new views, no traces *either of alkali or acid were apparent*, although the electro-chemical *action went on in the water as usual.* Thus vanished all the fine speculations on the power of electricity to generate new substances from water.

152. These highly intellectual and persevering inquiries became, in the hands of Davy, the germ of further and astonishing electro-chemical discoveries. Considering the immense influence of the negative wire in effecting a decomposition of the agate and glass vessels, and in calling up one of their constituent elements into the water they contained, he conceived that the same power which could subdue such stubborn chemical combinations as exist in the constituents of agate and glass, might subdue, if directed upon other compounds, combinations still more stubborn, and so be employed to resolve various kinds of substances into their constituent elements (137.) Such were the considerations that led to the immortal discovery of the resolution of the alkalies and earths into oxygen united to a metallic base, and showed them to be in fact nothing more or less than metallic oxides. Now, it was acutely imagined by this distinguished British chemist, that since in all cases of voltaic decomposition, alkaline and inflammable matter is invariably found upon the negative side of the apparatus, it was, therefore, highly probable that alkaline bodies contained an inflammable element,—a conjecture which soon after, in 1807, he fully confirmed.

153. Having exposed a thin piece of potassa to the moisten-

ing influence of damp air, he placed it between two thin plates of platinum, forming the electrodes of a powerful voltaic apparatus (38), (39). It became soon resolved into oxygen, and a highly inflammable and peculiar metalloid substance; the oxygen appearing as before at the anode, and the metalloid inflammable at the cathode (39). Soda yielded to the same wonderful agency, and became likewise resolved into a metallic base and oxygen. Thus was effected one of the most momentous and brilliant discoveries to be found in the annals of chemical philosophy, potassa and soda having been hitherto considered as elementary substances (137).

154. The metal obtained from potassa has been termed "potassium," and that from soda "sodium." In colour, these curious substances resemble silver or mercury. At common temperatures they are soft and plastic. Their disposition, however, to oxidate is so great, that they instantly tarnish on exposure to the air, and will detach oxygen from any substance containing it. They can only be preserved by immersion in naphtha,* or some other substance not containing oxygen. Potassium and sodium, notwithstanding their metallic character, are so light, that they float on water. When potassium is thrown on water, it immediately appears to inflame, decomposes the water, catches up its oxygen, and sets the hydrogen free. The combustion, on contact with the surface of the water, is a beautiful phenomenon. The flame is a mixed flame of white, red, and violet. The result of the combustion is to render the water alkaline. When moderately heated in oxygen gas, potassium also inflames, and potassa is reproduced.

Sodium also decomposes water violently, but does not appear to burn. When thrown on nitric acid, however, it burns with great brilliancy. Both substances unite with mercury in various proportions, and form amalgams, which

* A light and almost colourless oil, distilled from a viscous substance, termed petroleum. It is also a native combustible liquid, found in springs, on the shores of the Caspian Sea.

decompose water and act upon all the metals—even upon platinum.

155. The decomposition of potassa and soda may be completely effected with about 150 pairs of 4-inch plates, with double copper excited by one part nitric acid to thirty of water (72). With the two fluid batteries of Daniell (75), and other more modern arrangements, the result is easily attainable. A plate of platinum is to be connected with the negative side of the battery, and a thin piece of pure potassa or soda placed on it. We then bring another and similar plate of platinum, connected with the positive side of the apparatus, in contact with the upper surface of the potassa or soda. The alkali will soon appear to fuse at the points of contact, and metallic globules collect at the negative surface. Amalgams of potassium and sodium with mercury are readily obtained by placing a globule of mercury in a cavity cut in the surface of the alkali submitted to experiment. The alkali is now to be connected with the zinc extremity of the battery, and the mercury with the copper extremity. Very soon the mercury is converted into a soft solid, and, if thrown into water, will rapidly decompose it.

156. It may be here again observed, that previously to these discoveries, potassa and soda were considered as elementary bodies; but the volatile alkali, ammonia, had been resolved into hydrogen and nitrogen, in the proportion of three volumes of hydrogen to one of nitrogen. Now of these three alkaline substances, potassa and soda are considered as fixed alkalies, in contradistinction to ammonia, which is a highly volatile substance. Potassa and soda are obtained in burning to ashes various plants growing on the sea-shore, whilst the volatile alkali, ammonia, is obtained from a saline substance, separated by sublimation from soot; and called "Sal-Ammoniac." Pure ammonia is obtained from this substance under a gaseous form: it is rapidly absorbed by water, constituting what is termed liquid ammonia. This third species of alkali then may be considered as

a very wonderful substance, and from a great variety of circumstances possesses the highest interest. It is not a little remarkable, that of these three alkaline substances, whose properties as alkalies are so very analogous, two of them should turn out to be metallic oxides, and the remaining one a compound of two gases, totally distinct in character from the constituents of the other two. It has, therefore, been conjectured, upon fair inductive reasoning, that one of the gases constituting ammonia—probably nitrogen—although classed as an elementary substance, is really a compound substance having a metallic base, and that hence ammonia may at last turn out to be also a metallic oxide. Now, although the powers of the voltaic apparatus have not hitherto been so applied as to effect such a decomposition directly, still some approximation has been made towards it. If a moist cavity be formed in a piece of muriate of ammonia, commonly called sal-ammoniac, and a globule of mercury placed in it, then, on connecting the mercury with the negative side of the voltaic apparatus through a wire having a platinum termination in the mercury, and the sal-ammoniac with the positive side, a soft amalgam begins to arise, as in the case of potassa and soda (155). The globule of mercury emits a white smoke, its volume enlarges, and it throws out ramifications of apparently new matter. The amalgam thus obtained has a semi-solid consistence, and may be cut with a knife. The enlargement of the volume frequently amounts to ten times the volume of the mercury. This amalgam changes almost instantly by contact with the air, thereby showing that the base, hypothetically termed "ammonium," has the same disposition to combine with oxygen as evinced by potassium or sodium. When a portion of the amalgam is thrown into water, the water is rapidly decomposed. We have hence every reason to conclude that the volatile alkali ammonia is similar in its constitution to that of the two fixed alkalies, although its metallic base has not yet been obtained in a pure state.

157. Pontin, Berzelius, and Davy obtained in a similar way amalgams of barytes, magnesia, lime, and other earths; and it is hence to be inferred, that all these substances consist of oxygen united to a metallic base. These hypothetical metallic bases have been named after the respective substances which are supposed to contain them; thus, the metallic base of lime has been termed "calcium," of barytes "barium," of silex "silicum," and so on. Aluminum, the metallic base of alum, has been lately obtained in comparatively large quantity by a French chemist, M. Deville; who states it to be of a white colour, resembling silver, it does not tarnish, is malleable and ductile, and heavier than gold.

158. These beautiful researches must ever remain an imperishable monument of the immense importance of the voltaic apparatus as an instrument of chemical research; its operation in separating the constituents of substances, is unmistakeable in every variety of experiment.

Thus, if sulphuric acid, commonly called oil of vitriol, be placed in the circuit (39), fig. 18; oxygen gas is given off at the anode, and sulphur deposited at the cathode; phosphoric acid is converted into oxygen gas and phosphorous. Oils, alcohol, and æther, deposit charcoal, and give off hydrogen, and so on; no doubt therefore can remain as to the actual chemical constitution of such substances.

159. The following are some further instructive illustrations of the action of the pile in disuniting and determining the constituent elements of compounds to its opposite electrodes or poles.

Exp. 20. Let a solution of any neutral salt, suppose the sulphate of soda (called Glauber's salt), to be placed in separate glass cups, and the solution in each cup to be further united by some fibres of moistened cotton, as indicated (151) fig. 64; connect the fluid on each side with the poles of the apparatus as before: after a few hours the solution will decompose. The soda and acid, the constituents

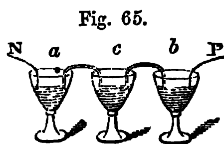
of the salt, will have become separated and transferred in opposite directions: the acid will be found in the cup connected with the uniting wire P, that is, at the positive electrode, and the acid in the cup connected with the uniting wire N, that is, at the negative electrode.

Exp. 21. Let one of the cups (151) fig. 64, contain a solution of a neutral salt, and place distilled water in the other; connect the glasses with moistened fibres as before, and the cup containing the dissolved salt with the positive wire P: complete the circuit by connecting the cup containing the distilled water with the negative wire N; in a short time the alkaline constituent of the salt will have become transferred to the distilled water at the negative electrode N, the acid constituent remaining at the positive electrode P.

Reverse the connections with the apparatus by placing the distilled water in connection with the positive electrode P, and the dissolved salt in connection with the negative electrode N, then the acid will be found to travel and become transferred to the positive electrode P, leaving the alkali behind at N. In either case the salt is decomposed.

Exp. 22. Place three glass cups, *a c b*, fig. 65, near each other, and connect them by fibres of moistened cotton, as *a c* and *c b*. Let a solution of some neutral salt, sulphate of potassa for example, be poured into the centre cup *c*, and a delicate infusion of blue cabbage leaves in the cups *a b*; complete the circuit as before through the wires P N. In a short time the salt will decompose, its sulphuric acid constituent will have passed into the positive cup P, turning the blue infusion in it red; whilst the alkaline or potassa constituent will have become transferred to the negative cup N, turning the blue infusion green.

Fig. 65.



160. It is to be observed, that in all these experiments

the constituents of the salts appear to have travelled through the moistened fibres connecting the vessels; and their particles seem, as in Exp. 20, to have passed in opposite directions either through or close to each other, without any combining affinity. So powerful is the apparatus in promoting this species of transfer and decomposition, that, in many instances, elements become transferred through bodies with which, under ordinary circumstances, they have the greatest disposition to combine, without undergoing the least change. Thus, by an arrangement similar to fig. 65, sulphuric acid in cup *b* may be transferred through a solution of ammonia in cup *c* to collect in cup *a*, without at all affecting the ammonia, or undergoing any change. In the same way, acids may be transmitted through delicate vegetable infusions without affecting them; alkalies, also: hence, supposing the theory of the transference to be admitted, there is evidently a total annihilation of the force called elective attraction, or chemical affinity (139) between the given substances whilst under the influence of the voltaic apparatus. Whether any more available theory of a series of decompositions and recompositions, similar to that of Grotthus (149), may be applied in explanation of these most astonishing phenomena, we have yet to learn.

161. In reviewing the history and effects of the voltaic apparatus, three speculative questions of great moment present themselves: first, the theory of the action of the pile; second, electro-chemical decomposition; third, the question of the identity of electrical and chemical force.

We have already considered the theory of the action of the pile (44) to some extent, and it hence only remains to treat more fully the questions of electro-chemical decomposition, and the identity of electrical and chemical force.

162. Davy having shown in his preliminary experiments, from 1800 to 1803 (37), that inflammable bodies, alkalies and metals, were always found on the negative side of the apparatus, and oxygen and acids on the positive side,

concluded, that this result depended on a peculiar electrical condition inherent in different substances, by which they are rendered either what he terms electro-*positive* or electro-*negative*. Thus acids are electrically negative in respect of alkalies. Zinc, as already observed (16), is electrically positive in respect of copper, and so of various other substances. He found, for example, by experiments similar to those originally instituted by Volta (14), that an acid and a metal after contact were in opposite electrical states,—the acid became negative, and the metal positive, conversely; taking an alkali and a metal, after contact, these states became reversed: the alkali here became positive, and the metal negative; hence he inferred that positive electricity has a tendency to pass from acids to metals, and from metals to alkalies; whilst negative electricity tends to flow from alkalies towards metals, and from metals towards acids. Davy, therefore, regarded various substances as naturally endowed with specific electrical energies or capacities, a notion entertained by other philosophers (10) engaged in this branch of science. A variety of experiments led him further to conclude, that in all cases in which substances combine chemically they have contrary electrical energies; and that hence, according to the laws of common electricity, such substances are attractive of each other; * the compositions and decompositions therefore produced by the voltaic apparatus depend really on the common laws of ordinary electrical attractions and repulsions, as above illustrated (149), fig. 62 in the theory of Grotthus; and that hence what had been hitherto called chemical attraction, affinity, or elective attraction (139), was really no other than common electrical force exerted between the particles of bodies instead of masses, as usually observed.

163. Although this theory was not at the time favoured with the entire confidence of scientific chemists, from a deficiency of all the experimental evidence which a perfect

* Rudimentary Electricity, (16). p. 13.

theory demands, it was, nevertheless, a theory which led to the grand result of the decomposition of the alkalies (153), and which finally obtained for Davy the annual prize established by Napoleon I. for the best experiments in voltaic electricity. According to this theory of electro-chemical decomposition, the attractive and repellent energies are communicated from particle to particle through substances placed in the voltaic circuit (39), fig. 18; the consequence is an ejection of the constituent elements of the substance at each pole of the battery, the poles of the series having a greater force of electrical attraction for these constituent elements than they have for each other: that, in fact, electro-positive bodies (162) are attracted by the negative extremity of the voltaic pile, and repelled by the positive; and, conversely, electro-negative substances are attracted by the positive extremity of the pile and repelled by the negative extremity,—a view of electro-chemical action virtually included in the theory of Grotthus (150), fig. 63. According to this theory, also, the heat and light resulting from intense chemical action is nothing more than the restoration of the electrical equilibrium, and is analogous to the production of the electrical spark between bodies charged with opposite electricities; a view afterwards recognised by the celebrated Berzelius, who adopted the identity of electrical and chemical forces as the basis of his chemistry.

164. We owe to the recent and masterly investigation of Faraday, as already observed (38), a more complete elucidation of the phenomena of the pile, and the nature of electro-chemical decomposition, than is to be found in the theory propounded by Davy. Having first identified the several various forms of electrical action, and proved them to be all emanations from one and the same general principle, he proves that electro-chemical decomposition is the result of current force operative within the electrolytical substance itself, and by which its constituent elements are

ejected, as it were, at the electrodes or poles of the voltaic series; that the hypothesis of attraction and repulsion in the poles or extremities of the apparatus is untenable, the force affecting the decomposition of any substance being within the body itself. When the voltaic circuit is complete through an electrolyte (41) (42), an electrical current is immediately established between the electrodes of the battery. This current is to be considered in the light of progressive force (23), and constitutes an axis of power having equal forces in every point in opposite directions. The elements of the given substance move in obedience to the respective determining directions of this current power, the *anions* in one direction and the *cathions* in another (41). It was upon this ground, as before stated (38), he was led to reject the term pole as accepted by Davy and other philosophers, and to substitute the term electrode in the general nomenclature already given (42) Table III. Now, the electro-chemical power of this current force is shown by Faraday to be exactly equal to the quantity of passing electricity evolved in the chemical action of the pile (51), which general proposition he more fully elucidates by means of the Voltameter (93). He further shows that the electro-chemical action is definite or of determinate amount; and so definite as to enable us to obtain numbers for every constituent element of a compound which may be taken as "electro-chemical equivalents." But what is to be more especially observed in this case is, that these electro-chemical equivalents, as thus deduced, are really the atomic weights of Dalton (140), the two are identical as chemical measures.

These electro-chemical equivalent numbers, then, represent the proportions in which "*anions*" or "*cathions*" are evolved during electrolytic action (41), and, consequently, their combining proportions, and they are always consistent with each other. Thus the number 8 will represent and be found to be true as the electro-chemical equivalent for

oxygen, whether separated from hydrogen in the case of the decomposition of water, or from tin or lead.*

165. Combining the theory of electro-chemical decomposition with the chemical theory of the pile, Faraday infers, as already observed (45), the production of the electrical current by the oxidation of the zinc, which current, in passing through an electrolyte (39), fig. 18, liberates its constituent elements, and ejects them at the opposite electrodes, so that the forces at the points of decomposition or recomposition are of the same kind, being opposed to each other through the rheophoric circuit, that is, through the wires and other matter conducting the current between the extremities of the apparatus; so far may this circuit be considered as really conducting chemical affinity. The chemical power of the voltaic pile, therefore, may be expressed by the term chemical affinity. The great conclusion of this eminent chemist and philosopher is; that the elements of compound substances are united or held together by a definite power, which may cease to exercise this function, and assume the form of an electrical current; and thus he goes far in establishing the identity of electrical and chemical action, which up to a late period remained an unsolved problem.

* Faraday's Exp. Res., p. 835.

CHAPTER VI.

HEATING EFFECTS OF THE PILE.

Notices of some of the more powerful and brilliant results of the calorific agency of the pile—Heating power dependent on the size of the plates—Experimental illustrations—Laws of the calorific action of the battery, and its effects on metallic wires—Heating effect dependent on the quantity of electricity transmitted in a given time—Relation of conducting power to the temperature and mass of the metal—Conducting power of different metals for the voltaic discharge; also for the ordinary electrical discharge—Results of experiments by Professor Riess, examined.

166. The agency of the voltaic pile, as a source of intense heat, is not a little remarkable and astonishing. The most refractory metals, when exposed to its operation, are ignited and fused; if beaten out into thin leaves, they burn with great brilliancy; when drawn into fine wires and placed in the circuit, they glow with a vivid white heat, or run into balls by fusion. They are not, however, dispersed, as in the case of fusion in a similar way, by the ordinary electrical discharge. The first powerful effects of this kind were produced by the large battery constructed by Mr. Children in 1809, consisting of twenty double plates, 4 feet by 2, exposed in a cellular trough to the action of diluted acids (71). When a platina wire, of $\frac{1}{30}$th of an inch in diameter, and 18 inches in length, was exposed to the action of this battery between bars of copper connecting its poles, it first became red-hot, then white-hot, until at length the light was insupportable to the eye. In a few seconds after this, the metal, unable longer to resist complete fusion, fell into small globules. Many metals, on exposure to the same ordeal, not only fused instantly, but vanished in vapour. With the battery of the Royal Institution (70) Davy

obtained similar results: when two pointed pieces of well burned charcoal, in connection with the poles of the battery, were brought nearly into contact, more than half the volume of the charcoal became ignited to whiteness, whilst on withdrawing them gradually from each other, a broad ascending brilliant arc of light followed of dazzling splendour; the form of this arc was that of two cones united at their bases; any substance introduced into it became instantly ignited. Platina, so difficult of fusion by ordinary heat, exposed to this voltaic flame melted as readily in it as wax in the flame of a common candle. Quartz, sapphire, magnesia, and lime all underwent fusion—fragments of diamond, charcoal and plumbago disappeared.* At a more recent period, Professor Daniell, with seventy cells of the constant battery (75), succeeded in fusing rhodium, iridium, and titanum, and other refractory metals. On repeating Davy's experiments with the pointed charcoal conductors, an arc of voltaic flame arose of such volume and intensity as to endanger the eyes of the spectators, although guarded by thick grey glasses. The Professor's face was scorched as if exposed to the burning effect of a hot meridian sun. When collected into the focus of a mirror, the rays emitted a heating power so great as to burn a hole through paper at a distance of some feet.

167. The power of the voltaic apparatus, as a source of heat, is much increased by massing together the plates of the series, so as to obtain as great an extent of metallic surface as possible under a few plates of large size. We owe this fact to the fine experiments of the celebrated French chemists Messrs. Thénard, Fourcroy, and Vauquelin. They found in the course of their investigations on the combustion of metals by the voltaic pile, that a battery of small plates, which did not evince any great heating power, readily burned metallic leaves when converted into a battery of a few plates having the same extent of metallic surface:

* Davy's Elements of Chemical Philosophy.

neither the force of the shock nor the electro-chemical energy, however, were at all increased by augmenting the size of the battery plates; these effects appeared to depend for the most part on the number of repetitions or alternations of the series.

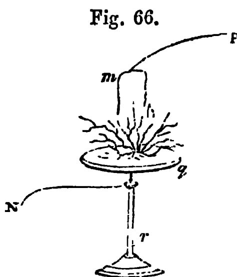
168. The great battery constructed by Mr. Children (71), although it evinced such astounding calorific power, had little or no effect on the living animal body, or in decomposing water, nor did it sensibly affect a gold leaf electrometer. Mr. Singer has supposed this remarkable circumstance to depend on an electrical action analogous to that observable in a Leyden battery, made up of jars of unequal dimensions. If such a battery be charged up to a given intensity, as indicated by the electrometer (114), then under this intensity each jar will contain very unequal quantities of electricity; the larger jars would have accumulated a much greater quantity than the small jars, and if selected and discharged together, would ignite a much greater length of fine wire than the smaller jars treated in a similar way; yet the shock from either of them would be pretty nearly the same. It is then the large quantity of electricity accumulated by the large plates which is really the source of the heating power, whilst the intensity of a smaller quantity of electricity accumulated by the smaller plates, is the source of the shock; this view of the source of the heating power of the pile, although in some degree imperfect, is still worthy of consideration: for however great we may suppose the comparative quantity of electricity discharged from voltaic batteries of an equal number of plates of unequal dimensions, it is clear that when operating upon a substance of comparatively low conducting power, and which *can only transmit a certain quantity*, the battery of small plates would be as efficient for its decomposition as one of an equal number of large plates. When operating however upon metallic bodies of high conducting power, which *can* transmit the accumulation, then the large quantity of

electricity is manifest by the heating effects, as will be presently seen (173).

169. The following may be taken as beautiful illustrations of the calorific powers of the voltaic apparatus.

Exp. 23.—Suspend a sheet of gold or silver-leaf, *m* (fig. 66), or a thin leaf of any other metal, to a stout wire, P, connected with the positive extremity of the battery, and immediately under it place a bright metallic plate, *q*, connected with the negative conductor N. Bring the leaf *m* gradually in contact with the plate *q*, either by raising the plate towards it through the insulating support *r*, or by depressing the wire P by an insulating rod; directly the leaf touches the plate, it begins to burn and scintillate with great brilliancy. Gold leaf burns with a vivid white light, tinged with blue; silver with a beautiful light of emerald green. Copper burns with a white light tinted blue, and emits red sparks. Lead emits a purple light, and zinc emits an effulgently white light of a blue cast.

Fig. 66.



Exp. 24.—Connect a piece of fine watch-spring pendulum wire with the positive wire P, fig. 66, and bring the free end of it in contact with a shallow plate of mercury, *q*, connected with the negative wire N. We may then observe a brilliantly vivid combustion both of the mercury and the wire.

Exp. 25.—Strain a fine iron wire of about 10 inches in length between two brass balls, supported on insulators of glass, in the way represented, *m n*, fig. 68 (177). Complete the circuit by connecting the balls with the opposite extremities, P N, of the battery. The wire—if the battery be powerful—will soon become red, then white, hot, and will eventually fuse into small balls. A fine wire of platinum, treated in this way, may be retained at a white heat for a

considerable time. If about 10 inches of platinum wire, of 1-50th of an inch in diameter, be thus strained between two metallic rods connecting the opposite electrodes of twenty cells of a Daniell's Battery (75), it will soon become white hot, and will continue to glow so long as the battery continues to act.

Exp. 26.—Pass a wire of platinum, of about 1-40th of an inch in diameter, through a small quantity of water or ether, contained in a glass cup, and connect it with the opposite poles of the apparatus as before; in a short time the water may be caused to boil, and the ether driven into vapour.

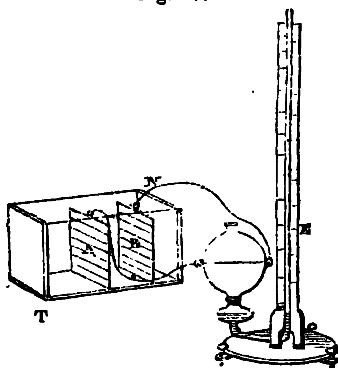
170. The heating and ignition of metals by the voltaic apparatus may, as already observed (83), be effectually employed as a means of estimating the power of a given battery, and the force of the electrical current. We must, however, in the application of this principle, take into consideration certain circumstances liable to affect the results of our inquiries, and lead to inaccurate conclusions. Faraday, in his researches into the heating effects of the current, observes, "A fine wire may be used as a rough but ready regulator of a voltaic current; for, if it be made part of the circuit, and the larger wires communicating with it be shifted nearer to or further apart, so as to keep it sensibly at the same temperature, the current passing through it will be nearly uniform." We may so far infer that the indicated heat in the wire is a measure of the quantity of current electricity passing through it. The diameter of the wire heated will depend on the dimensions of the plates of the battery (167). The length of it will be proportionate to the number of the series. From some valuable experiments by Walker, it is shown, that if the mean heating power of one battery be such as to heat z inches of a given metallic wire, then the heating power of any number of equal batteries united would heat n times z inches. Thus, if one battery could heat 5 inches

of platinum wire of a given diameter to a certain point of incandescence, then ten such batteries united could heat ten times 5 inches, or 50 inches, to the same degree of incandescence.

171. We have already described (84), (91), (92), several instruments by which certain comparative elevations of temperature in metallic wires, subjected to the voltaic current, may be measured. Of these, the thermo-electrometer (86), will be found perhaps the most available, especially for small degrees of heat. The author, in a paper which was honored by a place in the Transactions of the Royal Society of Edinburgh for the year 1831, further investigated, by means of this instrument, the heating effects of voltaic electricity on metal wires, and other important laws of voltaic action, to which Sir H. Davy, in his valuable researches relative to temperature and conducting power, had already, in the year 1821, called attention.* The following are amongst the results of these inquiries:

172. Two plates, A B, fig. 67, one of zinc, the other of copper, 7 inches high by 6 inches wide, and about 1-10th of an inch in thickness, were placed in a glass cell, T N, and connected by stout copper wires with the thermo-electrometer E, having a copper wire through the ball of 1-100th of an inch in diameter, as shown in the figure. The plates were equally divided by horizontal lines, and could be placed at measured distances from each other, so that when a dilute acid was poured into the cell, the heating effect of the

Fig. 67.



* Phil. Trans. for 1821. Part ii. p. 425.

voltaic force as depending on the quantity of metal immersed, or the distance of the plates, could be accurately observed. The dilute acid consisted of nitric and sulphuric acid, in equal parts, with forty-eight of water. The result of this experiment was, that the thermo-electrometer, E, gave indications of voltaic force, as the quantity of metal immersed directly, and as the distance between the plates inversely. When a second plate of copper was opposed to the other surface of the zinc plate, and the two copper plates united by a metallic band, as in Wollaston's arrangement (72), the effect on the thermo-electrometer, E, was very considerably increased; it was generally doubled. When additional copper plates, external to those, were added, a still further increase of power was obtained. Indeed, it appeared as if the new force brought into operation by the successively added copper plates was only limited by the respective distances from the zinc plate at which they were necessarily placed.

173. The simple law just stated (172), was apparent with the given wire in the ball under any amount of voltaic excitation of the two plates. When, however, an extremely fine wire, either of the same metal, or of a metal of an inferior conducting power, was employed in the ball of the instrument, then the law was no longer in every case apparent: the indicated force with a wire of about $\frac{1}{300}$th of an inch in diameter, no longer corresponded exactly with the increased power. This, on further examination, was found, as had been previously announced by Davy,* to depend on some peculiar condition of the wire, by which it was rendered incapable of transmitting a high current force. It was further observable, that when the voltaic power was small, then the *fine wire* was most heated, but when more considerable, then the *larger wire* became the most heated, evidently depending on the circumstance of the smaller wire not being capable of transmitting all the excited electricity. In confirmation of this, it was found that with

* Rudimentary Electricity (137), p. 163.

extremely fine wires of low conducting power, the indicated force of three cylindrical batteries conjoined, each exposing a square foot of zinc, with double copper (73), was no greater than with a single battery; whilst with larger wires in the ball, of high conducting power, the results were constantly proportionate to the increased power.

174. As the diminishing proportionate effect with an increased power when a very fine wire is employed in the thermo-electrometer E, fig. 67, evidently depends on its inadequacy to transmit a certain quantity of electricity in a given time; it seems reasonable to infer, that imperfect conducting fluids, or extensive lengths of very fine wire, may approach an insulating effect for this species of electricity, and such is really the case: little or no heating effect was apparent when a long spiral of fine wire covered with silk was introduced into the circuit, and none whatever when a portion of the circuit consisted of water contained in a tube of glass.

This result is in complete accordance with the results of Davy's previous researches in 1821, who observes, that "In a battery where the quantity of electricity is great and the intensity low, charcoal made to touch only in a few points is almost as much an insulating body as water, and cannot be ignited, nor can wires of platinum of less than $\frac{1}{81}$th of an inch in diameter, and three feet in length. A foot of platinum wire is scarcely heated by such a battery, whilst an equal wire of silver becomes red hot, and the same length of thicker platinum wire becomes intensely heated."

175. Much care is requisite in speculating on these interesting phenomena, which appear to be intimately associated with the occult causes of heat and electricity. We may however fairly conclude, from these experiments, that the heat excited in any substance by the voltaic battery will materially, if not altogether, depend on the quantity of electricity which passes through it in a given time, that is to say, upon the velocity of the current. Time is certainly

an element to be taken into calculation in our investigation of these curious effects. The author endeavoured to find, by a variety of experiments, whether, by increasing the dimensions of the wires in the ball of the instrument, any ratio greater than that of the simple ratio of the increased power could be obtained, but without any new result. Now it is worthy of remark, that in the parallel case of electrical discharge from the Leyden battery, the heating effect, as indicated by the thermo-electrometer, is as the second power or square of the quantity of passing electricity.* The difference in these two kinds of electrical discharge may be conceived to arise out of the peculiar character of what we may term electricity of high tension. In the case of the ordinary electrical discharge, the impulsive action is such as to break through all resistance, and cause a finite accumulation to pass through the wire in times inversely proportional to the quantity of electricity accumulated. Thus, a double quantity of electricity accumulated on coated glass, and discharged through a metallic wire of given dimensions, may be conceived to pass through the circuit in one-half the time of a unit of quantity accumulated and discharged under similar circumstances. Three times the quantity accumulated may be conceived to pass in one-third the time, and so on. If, therefore, the heating effect varies with the quantity directly, and with the time inversely, we should have necessarily a resulting compound effect; and hence, the heating power would in this case appear to be as the square of the accumulation, that is, as the square of the increased power; and this, as we have shown in our "Rudimentary Electricity," is altogether independent of the electrometer indications termed intensity (114) (115). Now, in the voltaic discharge we may conceive the time to remain constant for all degrees of power; that is to say, we may imagine a small current force *as to quantity* to traverse a given circuit in the same time as a strong current force, the

* Phil. Trans. for 1821. Part ii. p. 425.

resistance to a small force being less in proportion. The heating effect in this case will vary with the quantity, that is to say, it will be only in the simple ratio of the increased power. It was further observed, in employing great lengths of circuit, that with the same voltaic battery the indicated effect on the instrument was inversely proportional to the length of the circuit. The same law obtains with ordinary electrical discharges upon extensive circuits varying from 300 to 900 feet.*

176. These experiments, together with the previous experiments by Sir H. Davy, evidently go far in determining the limit of the quantity of voltaic electricity which metallic wires can transmit under certain circumstances, and which being so far determined, enables us to arrive experimentally at the different degrees of conducting power, either of the same or different metals, and to investigate other relations of this power to magnetism and heat. As already remarked (89), the indications of the thermo-electrometer may be always taken as a measure of the variations of conducting energy, or of the force of a voltaic combination, so long as we employ a thermometer wire in the ball of the instrument of such dimensions as will give indications proportionate to the increased power. Thus, if the degrees of elevation of the fluid correspond with the increased quantities of metal in operation, or nearly so, supposing the voltaic combination to be a single pair of plates (136), fig. 67, we may fairly presume that the instrument will indicate a variation of force upon the whole any how produced.

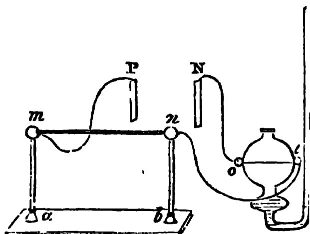
With a view of investigating the effect of heat on the conducting power of metals, as also the relation of conducting power to the mass of metal employed, and the relative conducting power of the various metals for voltaic electricity, the following experiments were resorted to:

177. *Relation of conducting power to temperature.* A small copper wire, *m n*, fig. 68, about six inches in length,

* Trans. R. Society for 1834, p. 228.

and about the 1-80th of an inch in diameter, being placed on insulating glass rods, *a m*, *b n*, was introduced into the circuit, P *m*, *n t*, *o* N, of which circuit the thermo-electrometer E formed a part: the metallic connections with the battery, *m* P, *n t*, and *o* N being stout copper wires, and the contacts made very complete. The voltaic battery consisted of about two square feet of zinc, with double copper as a cylindrical battery (73). On transmitting the current through *m n*, the index fluid of the thermo-electrometer E attained a given altitude. The flame of a spirit lamp was now applied to the wire *m n*, so as to heat it. The effect was so to retard the discharge as to cause the fluid to descend along the scale E, thus evincing a diminished effect on the wire in the ball; when, on the contrary, the wire *m n* was cooled down by ice, or the evaporation of water or ether from its surface, then the contrary results ensued. The thermo-electrometer showed an increasing power, and the fluid rose to a much greater height, thus confirming the general result arrived at by Sir H. Davy, that "*the conducting power of metals varies with the temperature, and is lower in some inverse ratio as the temperature is higher.*" *

Fig. 68.



178. It does not much matter in this case how the heat in the metal is excited. The same result ensued in heating the wire *m n* by the voltaic discharge of a second battery. This was very pleasingly shown by means of a second thermo-electrometer, the wire of which was substituted for the wire *m n*, exposed to the current force of both batteries, which by one particular arrangement of the connecting wires could be easily managed. In this case, the two instruments appeared to vibrate as a sort of delicately poised balance, the

* Phil. Trans. of the R. S. for 1821, p. 431.

slightest change in the one being accompanied by an opposite and corresponding change in the other.

179. *Relation of conducting power to the quantity of metal.* In this investigation, the given metal, the subject of experiment, was drawn into a wire of a given diameter, and being passed through a cell of water, was placed in the position of the wire *m n*, as in the last fig. 68, so that its temperature might not change whilst transmitting the current. When wires of three different metals, copper, platinum, and lead, whose diameters varied from the '01 to the '025th of an inch, were placed in the circuit, the indications of the thermo-electrometer E were as in the following table:—

TABLE IV.

No. of wire and ratio of diameter.		Metals and indicated thermometer degrees.		
Wires.	Diameter.	Copper.	Platinum.	Lead.
1	1	60°	43°	36°
2	0·75	60°	36°	27°
3	0·5	40°	21°	18°
4	0·25	15°	4°	2°

180. It may be seen by a reference to this table, that the smallest copper wire No. 4, as compared with the largest copper wire No. 1, indicated a degree of conducting power for voltaic electricity in the simple ratio of its diameter, that is, as 1 : 4. The same is observable in copper wires No. 2 and 3 : here the indications of the instrument were as 2 : 3. The conducting powers however of copper wires No. 1 and 2 appear, from the quantity of electricity transmitted, to be nearly alike; so that the differences of the amount of metal is not in this case apparent.

181. On comparing the relative thermometer degrees of the less perfect conductors, viz., platinum and lead, we see that for the wires 1, 2, and 3, the conducting power is exactly

as their diameters, or very nearly so. With the smaller wires however of these metals, platinum and lead, No. 4, the transmitting power became so small for the quantity of electricity in action, as not to admit of any accurate deduction from them. The lead wires No. 1 and 4 are nearly in the inverse ratio of the square of their diameter.

182. The general conclusions arrived at by an extensive series of experiments of this kind were, 1st. That for certain given small forces, each metal is an equally efficient conductor; 2nd. That the differences in conducting power of the various metals for voltaic electricity become more and more apparent up to a certain limit, as the force of the battery increases; but the exact proportions in which these differences increase with the increased power were not fully determined.

183. *Relative conducting power of various metals for voltaic electricity.* In this branch of voltaic investigation, we have to take into account the laws of action apparent in the previous experiments, and which are possibly the source of the differences in the order of the metals as conductors of voltaic electricity arrived at by various philosophers, whose valuable researches have so greatly enriched this branch of science.* The order of succession of a number of different metals as conductors of voltaic electricity, treated as before (179)—that is to say, when substituted for each other successively in the circuit *m n*, fig. 68, and by other arrangements,† (177)—appeared to be as follows:—

TABLE V.

Order of succession of the Conducting Power of various metals.

1	2	3	4	5	6	7	8	9	10	11
Silver	Copper	Zinc	Gold	Tin	Iron	Platinum	Lead	Antimony	Fl. mercury	Bismuth

* Becquerel, Traité de l'Electricité, vol. iii. p. 74.

† Antimony and bismuth were cast into small bars, and compared with

184. This order, with the exception of tin, is nearly the same, for the greater part of these metals, as that determined by the author for the ordinary electrical discharge in the year 1826, and is, with few exceptions, upon the whole generally accordant with the results of other experimentalists. The order of conducting powers above given was obtained from wires of about 1-50th of an inch in diameter, and about 6 inches in length, and were all placed in a cooling fluid medium, so as to preserve them at a constant temperature. The battery employed was such as already stated (177), viz., a cylindrical battery, exposing about two square feet of zinc, with double copper, and excited by dilute nitric and sulphuric acids, in the proportion of 1 combined acids, in equal parts, to 50 water. Davy, in his experiments in 1821, found the conducting power of tin between that of gold and iron; the many disturbances, however, liable to arise in this class of experiment, owing to the variable conditions of different arrangements, as regards voltaic force, the transmission of the current by the given metal, &c., will always interfere with a determinate result. Upon the whole, the results in Table V. are not far different from those of Sir H. Davy.

185. In these experiments the several metals were placed outside the thermo-electrometer, a method subsequently followed by Professor Riess in his researches, printed in the Annales de Chimie, for 1838. Taking, however, the comparative temperatures of the several metals under the operation of a given voltaic discharge, as being inversely proportional to their relative conducting powers; then, as in the author's experiments in 1826, we may investigate the relative conducting powers of several metals, by drawing them into wires and placing them inside the ball of the instrument. In this case, however, it will be requisite to employ wires of sufficient dimensions to transmit freely the current force of the battery, otherwise, as already observed

copper as a standard similarly treated: fluid mercury was treated in a similar way, by a groove in varnished wood.

(173), the best conductor may, under some circumstances, appear to be the most heated.

186. The great variation liable to arise in the treatment of metallic wires in this way by the voltaic discharge does not allow, as just observed, of any very definite general determination as to the precise degree of conducting power of the several metals, or enable us to say, *how much* the conducting power of one metal exceeds that of another. We can only arrive at such a deduction, relatively; that is with regard to the current force to which the given metal is exposed. Much on the same principle as in deducing the order of succession of the electro-motive force of various substances (82), we have to take into the account the particular exciting fluid employed. In dealing, however with the ordinary electrical discharge from the Leyden battery, we may approximate very closely to a precise measure of the relative conducting power of various metals. Thus the author has shown experimentally (Phil. Trans. for 1826), that taking the conducting power of silver or copper as unity, then the conducting power of copper to iron, would be as 5 : 1, that is to say, copper would have five times the conducting power of iron; and would, under the same degree of heat excited in it, transmit five times the quantity of electricity. Similarly, the relative conducting powers of copper and gold are as 3 : 2, of copper and lead as 12 : 1, and so on. These results are not without great claims to confidence, corresponding as they do generally with the early deductions of many celebrated experimentalists. Dr. Priestly observes, that an electrical explosion, which only melts a copper wire of a given diameter, would quite dissipate an iron wire of twice that diameter. The order of the fusibility of metals by the Leyden battery as deduced by Van Marum, was lead and tin, iron, gold, copper or silver, which is precisely the same order of the heating effect as deduced in my paper in the Phil. Transactions for 1826. Taking the conducting power of lead as unity, the order of

succession and relative conducting powers of the following metals, supposing the whole of a given accumulation, in a Leyden battery to be forced through them, are as in the following table:—

TABLE VI.

Metals . . .	Lead	Tin	Iron	Platinum	Zinc	Gold	Silver or Copper
Conducting Power	1	2	2·4	2·4	4	8	12

In the experiments of Van Marum, which were pushed up to the point of fusion of the metals, the degrees of conducting power exhibited much greater differences, although the order of succession is the same, which may be attributed to the imperfect methods of experiment in these early periods of quantitative electrical measurement.

187. The heating effect of the same or different quantities of electricity on metallic wires, momentarily discharged through them, under the form of an ordinary accumulation on coated glass, is, as already observed (175), directly as the square of the quantity of electricity, without regard to the intensity indicated by the common electrometer; it is also as the square of the diameter of the wire inversely, that is, as the quantity of metallic matter inversely, so that the conducting power of a metal for ordinary electricity, varies with the area exposed in cutting it through transversely to its length, that is to say with the area of its section, since this will be proportionate to its solid contents.

The resistance to the passing accumulation will increase with the length of metal traversed, a law which I found obtain through a circuit of from one hundred up to one thousand feet.*

188. The explanation of these general laws of electrical action may be thus stated. Supposing a given quantity of electricity to fall on a single metallic particle, and to

* Phil. Trans. for 1834, p. 228.

experience a given resistance in its progress, then supposing a second similar particle to be placed by the side of this first particle, this resistance would become only half as great, since the charge would be divided between the two particles. If two new particles be added, we may conceive the resistance to be still further reduced in the same proportion, and so on inversely as the number of added particles brought to share in the conduction. Now, in the sections of wires, the areas exposed will be as the squares of the diameters of the circles; hence, in a wire of twice the diameter, we have four times the area, or number of metallic particles; the comparative resistance, therefore, in such a wire is only one fourth; hence the heating effect, as found by experiment, becomes reduced in the same inverse proportion. Similarly, by increasing the length, we continually increase the number of metallic particles, or resistances, to be successively vanquished by the same quantity of electricity taken in a right line; hence the resistance through twice the length of circuit will be twice as great,—through thrice the length three times as great, and so on. If the quantity of electricity discharged be increased, we have a resistance proportionate also to the increased force of the accumulation. Thus, a particle of metal transmitting a double quantity of electricity is subject to a double force, the tendency of the opposite electrical powers to unite, always increasing with the amount of the electrical disturbance, that is, with the charge of the battery. Such are the results with the ordinary electrical discharge, although from the causes already explained (179), the inverse proportion of the square of the diameter of the wire is not always apparent in voltaic discharge.

189. Professor Riess, of Berlin, as already observed (90), has objected to some of the results just stated (187). He thinks the heating power of the ordinary electrical discharge is dependent on the amount of coated glass upon which the electricity is accumulated, and has thrown the failure of the deduction of such a result from experiment upon an assumed

defect in the construction of my instrument.* It is, however, extremely easy to discover in the memoirs of this celebrated philosopher the source of his misapprehension. The question is an interesting and important one, and demands a brief notice here; it is a question of a law of electrical action of great generality, viz.: that the same quantity of electricity always produces the same effect, without any reference to its previous electrical indications.

Thus I have shown,† that the heating effect of the electrical discharge is entirely dependent on the quantity of electricity discharged through it, without regard to the intensity evinced by the battery, or whether accumulated on thick glass or thin. In accordance with this deduction, and to which Professor Riess objects, it is further shown by Faraday (Expl. Researches, 366 and 367), that "If the same absolute quantity of electricity pass through the galvanometer needle (98), whatever may be its intensity, the deflecting force is the same," and "that the chemical power, like the magnetic force, is also in direct proportion to this absolute quantity of passing electricity;" so far the results of my experiments with the thermo-electrometer are quite in accordance with the deductions of one of the most distinguished philosophers of this or any other country. A question here arises, as to what is meant by the term "intensity." We have already discussed that question (113) as regards common electricity; but whether we accumulate a given quantity of electricity on thick glass or thin, on a greater or less extent of coated glass, the whole of it at the instant of discharge concentrates in bulk upon the wire through which it is discharged, and hence its heating effect is quite independent of any variable indication of an electrometer placed in conducting connection with the battery; and which, with the same quantity accumulated, may, by

* Ann. de Chimie for 1838, vol. lxix. p. 111; and Poggendorff, Annal der Phys. Th. iv. p. 432.

† Trans. of the Plymouth Institution, p. 66, exp. 17 and 18.

varying the conditions of the experiment, indicate any intensity we please. These intensity indications, as they are termed (114), afford no information whatever as to any *quality* of the electricity accumulated. In fact, they in no way measure the absolute tension of the accumulation at the instant of its *concentration* upon the wire; they merely indicate what may be termed its freedom of electrical action, taken in terms of an attractive or repulsive force with relation to the surface over which the charge is expanded. Now, it may be shown, that this intensity indication varies inversely with the square of the surface, all other things being the same; that is to say, if you dispose the same quantity of electricity on twice the extent of coated glass of the same thickness, the electrometer only evinces one-fourth the force.* The expression representing the attractive force of the accumulation as regards the quantity of electricity and the surface of coated glass upon which it is expanded will be, $I = \frac{Q^2}{S^2}$ in which I = intensity, or attractive force; Q = the quantity of electricity, and S = the extent of coated glass. Now, in discharging the given accumulation through a metallic wire, we find that the heat excited in the wire varies with the square of the quantity of electricity, all other things being unchanged, so we have the expression $F = Q^2$, calling F = the heating power of the discharge on the wire. Professor Riess, however, contends that the extent of surface, or "number of bottles," upon which the electricity is collected, and by which the *intensity* is diminished, must be considered; and that the heating effect is really $F = \frac{Q^2}{S}$. But if the effect varied in any inverse ratio of the intensity, it must be as $\frac{1}{S^2}$, because, as just stated, the intensity is as the square of the surface, or "number of

* Phil. Trans. for 1834, p. 223.

bottles," inversely; so we should have $F = \frac{Q^2}{S^2}$, which is evidently not the case, by Dr. Riess's own experiments.

190. It is true, as Professor Riess observes, that the effect on the wire will be less as the number of bottles or jars of the battery are increased, the quantity of electricity being constant; as I have myself fully explained in my paper in the Memoirs of the Plymouth Institution, printed in 1830, now twenty-five years since. But this result in no way depends on the electrical intensity; it is entirely dependent on the increased circuit or extent of metal traversed by the charge, in consequence of the increased number of charging rods, and other metallic connections necessarily attendant on an increase of the number of jars. The same result would ensue, if, in discharging an electrical accumulation from a single jar, we first discharged it through a circuit of 10 feet, and then through a circuit of 40 feet.* To make an exact comparative experiment, we should discharge the same quantity of electricity from single jars exposing unequal coated surfaces, the circuit being in each case alike.† Let, for example, a very large jar be first coated up to an extent of 2·5 square feet, and a given quantity of electricity accumulated and discharged from it, and be then coated up to 5 square feet, or double the former surface. Then let the same quantity of electricity be again collected and discharged from this double surface. Still, the effect upon the metallic wire will be the same, although the intensity will be only one-fourth in the case of the double surface. Dr. Riess is undoubtedly correct in his deduction relative to the number of jars, as I have myself shown,‡ but is evidently incorrect in his interpretation of the experiment, and has certainly no ground for assuming a defect in my instrument. In fact, the instrument gives the result, $F = Q^2$, for the nume-

* Mem. of Plym. Inst., exp. 17 and 18, p. 66. † Ibid. p. 71.

‡ Trans. of R. S. for 1834, p. 220. Trans. of the Plymouth Institution, p. 65 (21).

rator of Dr. Riess's formula, and, so far as the mere number of jars are concerned, would give the result corresponding with the denominator, if we put s = "the number of bottles," equal to c = circuit; but this is by no means a new result: that the heating effect of the ordinary electrical discharge on a metallic wire is directly as the square of the quantity of the accumulation, and inversely as the length of the circuit, has been repeatedly demonstrated in my several papers on this interesting question. The result, however, is not correct for the denominator, *considered as intensity*, that is, supposing the coated surface not increased by the addition of jars to the battery, as in the experiments by Professor Riess, but by increasing the coating of the same jar, or by employing two or more jars of unequal areas. Now, why the instrument should be true for the numerator of Dr. Riess's formula, and false for his denominator, it may be difficult to explain, except upon the evident misapprehension of the nature of the question under consideration. As already observed (90), there is not any well determined law of electrical action with which the indications of the thermo-electrometer do not coincide.

191. Important differences arise in experiments of this kind, in employing batteries of large and small jars, or in operating with greater or less quantities of electricity. The battery employed by Professor Riess appears to have consisted of five jars or "bottles," each exposing about a square foot of surface. Now, the addition of the charging rods as the number of "bottles" are increased, upon so small a surface, would be necessarily felt in the transmission of the accumulation; they would, as found by Dr. Riess, prove a serious impediment to the progress of the current. In a battery of five jars which I have recently employed, charged by a three-feet plate machine, each jar contained as much coated surface as the whole battery employed by Dr. Riess. In this case, large quantities of electricity were accumulated, so that the obstacles arising from the metallic rods necessarily

introduced into the circuit as the number of jars were increased, became of much less importance. When two jars only were employed, and placed horizontally with their open mouths against each other, and having a charging rod common to both, it did not appear of much consequence whether the accumulated electricity was collected and discharged from one jar or two. In operating with a battery of six jars, of Cuthbertson's construction, each exposing about 1·4 square foot of coating, the differences arising in accumulating a given quantity of electricity on one, two, three, &c. jars, amounted to something considerable. They were as follows:—

TABLE VII.

Number of jars . .	1	2	3	4	5	6
Heating effect in degrees .	16	11	9	7	5	3

It may, therefore, be supposed that, by increasing the number of jars, with a given accumulation, the effect on the thermo-electrometer would at length be inappreciable, and such was found to be the case; all this, however, has no relation whatever to the electrometer indication of the battery called "Intensity."

192. The fact is, that we do not obtain the full effect of the discharge due to an increasing quantity of electricity, when we increase the number of jars at the same time. The expression, $F = Q^2$ (175), is only true by experiment, for a constant coated surface, consisting either of a single jar or of two or three, &c. jars. In the battery just adverted to, the effect of double the quantity of electricity disposed on two jars only equalled about 2½ times the effect, instead of 4 times, which it would have produced when collected on one. When three times the quantity was disposed on three jars, the effect was about 4½ times as great, instead of 9 times, and so on, until at last a limit is reached

beyond which the advantage derived with a given battery from an increased quantity of electricity, is entirely neutralised by the obstruction of the metals of the added jars to the free transmission of the discharge.

193. In these experiments the quantities of electricity were measured by an exploding electrometer connected with the outside of the battery, which was insulated precisely in the way mentioned by Dr. Riess. The experiments were instituted so long since as the year 1828, and will be found in the Memoirs of the Plymouth Institution for 1830. I was not at the time aware that Colonel Haldane had resorted to a similar method of measuring the charge of the Leyden battery many years previously, viz., in 1797, as quoted by Dr. Riess, with the exception of the employment of Cuthbertson's scale-beam electrometer instead of a small jar with Lane's discharging electrometer, as used in my experiments. The most accurate measure of quantity accumulated in a Leyden battery is the unit jar which I subsequently invented, in 1831, described "Rud. Electricity," (93), page 105; also "Transactions of Royal Society for 1834," page 217.

CHAPTER VII.

CURRENT MAGNETIC FORCE.

Elementary Magnetic phenomena—First notions of the identity of Electrical and Magnetic forces—Discoveries of Oersted, his conjunctive Wire joining the Poles of the Battery—Relative directions of the Wire and Magnetic Needle, reciprocal attractive and repulsive forces—Development of Magnetism about the conjunctive wire in perpendicular circular planes—Electro-magnetic Needle—Action of Helical coils on Iron and Steel—Electro-magnets, their immense power—Development of Electricity by the induction of current Electricity and Electro-magnetic force—Primary and secondary coils—Electro-dynamic coils by Hearder and Ruhmkorff.

194. The magnetic agency of the voltaic apparatus is another of those singularly interesting and magical powers in which it so richly abounds, and may be considered as a most important link in the chain which evidently connects the unknown physical causes of heat, electricity, and magnetism, and probably other of those occult forces by which the material universe is controlled and regulated. It may perhaps conduce to a clearer apprehension of this very wonderful branch of voltaic electricity, if we briefly revert to some of the more elementary features of common magnetism, as given in our rudimentary treatise on that subject, leaving a more elaborate exposition of its principles to a study of that work.

195. It is here to be remembered, that a certain ore of iron, termed natural magnet or loadstone, has the power of aggregating ferruginous matter about given points of its surface. Iron dust, or filings of iron and steel, for example, will collect about and appear to be attracted by those points, in considerable masses. When this substance is suspended by a delicate thread, so as to have freedom of motion, then the points of its surface about which the ferruginous matter

collects are observed to arrange themselves so as to stand nearly in the meridian of the place in which the experiment is made. These points have been hence termed the poles of the loadstone; that part of the surface which points toward the north has been termed the north pole, and that portion of the surface directed towards the south, the south pole.

This understood, we have next to observe, that when a regularly formed bar of tempered steel of moderate dimensions, or a common needle, is brought into contact with the poles of the loadstone, and passed across them a few times with slight friction, then such a bar acquires properties similar to the loadstone itself, and constitutes what has been termed an artificial magnet. When worked into a certain form, and suspended on a fine central point, the bar becomes a magnetic needle. It is usual to mark that extremity of a magnetic bar which points toward the north, with a small cross, or a straight transverse cut. We have next to remember, that the magnetic energy or attractive force on ferruginous matter, is greatest near the ends of the needle, and that it diminishes in each half of it as we approach the centre, or nearly the centre, where it is little or nothing.

196. When two such bars or needles are placed upon fine pivots near to and immediately over each other, they will only rest in one position, that is, with the marked pole of the one over the unmarked pole of the other; if we attempt to place the two marked ends or the two unmarked ends over each other, and leave the needles to the free operation of the forces operating on them, they will not endure that position for a moment—the similar poles will repulse each other, and the dissimilar poles will attract, until they rest in the position just stated, that is, with the marked pole of the one over or next to the unmarked pole of the other.

197. Moreover, we find that when a delicate needle of tempered steel, not magnetic, is mounted on a fine transverse axis, so as to allow of motion in a vertical plane,

and is so nicely balanced as to be indifferent as to any position in that plane in which it may be placed, and, being so poised, is then touched with a magnetised substance, it will immediately, if in the plane of the magnetic meridian, take a given inclination to the horizon. Its marked pole in these latitudes will dip or incline to an angle of nearly 70 degrees. This dip varies in different latitudes; it is greatest near the pole, and nothing at the equator. The natural position of the magnetic needle, therefore, is not always a horizontal north and south line, but an inclined line, depending on the latitude nearly. An instrument for determining the amount of this inclination has been termed a Dipping-needle.

198. The natural cause of all these phenomena has been referred to magnetic properties in the mass or surface of our terrestrial globe, which has been imagined to have its opposite poles and magnetic centre in common with artificial magnets. In fact, the earth is probably a terrestrial magnet of some kind, giving inclination and direction to the magnetic needle. Perhaps upon the law of magnetism just explained, viz., that opposite poles attract, and similar poles repel, it would so far be really the south pole of the needle which would be attracted by the north pole of the earth; hence, that extremity which points north should properly be called its south pole. To avoid confusion of this kind, Faraday concisely distinguishes the poles of a magnet-needle or bar by the terms "marked" and "unmarked" poles; he speaks of the north and south ends of the bar or needle, but not of north and south poles of the needle.

Such are the elementary phenomena of common magnetism we have to keep in view in our expositions of the current magnetic force of the voltaic series.

199. The great similarity of the laws and physical relations subsisting between electricity and magnetism, as set forth by Œpinus: the proved identity by Franklin of the cause of lightning and common electricity, both of which can

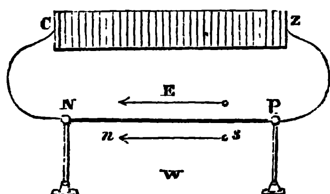
disturb the magnetism of the compass, reverse its polarity, and give magnetic power to steel, had long engaged the attention of the scientific world, and had suggested the notion of magnetic and electrical phenomena being more or less dependent on the same physical agency. The views, however, generally advanced upon this subject were very conjectural, and ill-defined, and had but little claim to consideration, further than that of interesting scientific speculations unreduced to the form of a science. We owe the present advanced state of our progress in these most important questions entirely to the wonderful magnetic powers of the voltaic apparatus, and its operation in determining the actual relations subsisting between the electrical and magnetic forces.

200. The first substantial discovery of the magnetic force of the voltaic apparatus was effected by Œrsted, a Danish philosopher of singular skill and ability. Having for some time turned his attention to the relations subsisting between electricity and magnetism, he was led, by that energy of intellectual thought so characteristic of a high order of genius, to consider, and examine, the actual condition of a metallic wire connecting the poles of a voltaic battery whilst in a state of activity. Then it was that a magnetic condition of the wire became apparent, never before contemplated. The wire, as already stated (96), caused the magnetic needle to deviate from its meridian according to given laws, and tend to place itself across the wire. On bringing the needle into various positions relative to the wire, either above or below, or on either side of it, always preserving the parallelism of the needle and wire, then it became apparent that the movements of the needle took place in a circle about the wire, as is seen in the following experiment.

Exp. 23. Let C Z, fig. 69, be a voltaic battery consisting of about 30 pairs of 6-inch plates, zinc and copper (68), and Z P N C a metallic wire connecting Z C, the zinc and copper extremities of the series, and of which the portion P N is

perfectly straight, and placed on insulating supports in the magnetic meridian. Let *s n* be a small magnetic needle (195) delicately suspended on a central point, and the voltaic current be supposed to flow from P to N, through the circuit Z P N C. If now the needle *s n* be immediately under and parallel to the joining wire P N, that is, if the wire be immediately over the needle, then the extremity *n* of the needle, next the negative extremity N C of the battery, turns towards the west, and that whether the needle be on the one side or on the other side of the wire, so that it be below and parallel to it. If the needle *s n* be now brought into the same horizontal plane P N as the wire, then these deviations are no longer apparent, but the needle attempts to move in a vertical plane perpendicular to the plane of the wire, and when suspended on a delicate horizontal axis admitting of this motion, invariably does so. Supposing P N to be the line of the magnetic meridian, N being the north end of it. Then if the needle be placed on the same plane as the wire on the west side W, the pole *n* next the negative side N C of the battery dips below the plane of the wire, and the opposite pole *s* is elevated. If, on the contrary, the needle *s n* be placed in a similar way on the east side E of the wire, then the reverse of this takes place; the pole *n* adjacent to the negative side of the battery is elevated, and the opposite pole *s* depressed. If the needle be now brought so as to be above and parallel with the wire P N, we have then the reverse of what happens when it is beneath the wire; the pole *n*, next the negative side of the battery, now turns toward the east, no matter whether it be on the one side of the needle or on the other, so that it be above and parallel with it.

Fig. 69.



201. Such were the first results of Œrsted's momentous experiments. His formula for the movement in a horizontal plane is this. "The pole above which the negative electricity enters is turned to the west, and the pole under which negative electricity enters turns to the east." The views of these phenomena, as given by Œrsted, are the following: he considers that in the voltaic discharge through the closed circuit Z P N C, fig. 69, opposite electricities enter the conjunctive wire at P and N; positive electricity is supposed to enter at P, and negative electricity at N. The result of this is a sort of electrical conflict within the wire, in which the two forces become so blended as to escape all observation by ordinary electrical instruments, without, however, acquiring perfect equilibrium, nevertheless, continuing to exhibit great activity under a new form of action sensible to the magnetic needle. These phenomena, it is to be remarked, are not the result of electricity at rest, that is, statical electricity, but are the consequences of electricity in motion, or dynamical electricity; the state of the conjunctive wire being a *dynamical*, not a statical state.

202. It may, perhaps, be as well further to observe, that in the experiment as illustrated in the last fig. 69 (200), we have, for the sake of historical association, employed a series of plates under the simple form of a common battery. The results in this case may hence appear not to coincide with the results of a single pair of plates, given (96) fig. 44. On referring, however, to our explanation of the real import of the terminating plates of a trough battery (34), it will be immediately seen that the two electrodes of voltaic discharge are the same in both cases. The last zinc plate Z in fig. 69 is only the positive side of the battery in virtue of its transmitting the positive electricity of the copper plate before it; and the first copper plate, C, is only the negative side, from its transmitting the negative electricity of the last zinc plate behind it. The terminating zinc and copper plates are therefore not to be considered, except as adjuncts

designating the positive and negative extremities of the pile. Take these away, and the terminating plates in figs. 69 and 44 are the same.

203. It is evident that, in all these operations, the directive force of the needle and the way in which it is suspended are two forces interfering with what would be the actual movement of the needle, supposing such forces neutralised or removed. In this case we find, that when the centre of a finely-hung needle is brought near the conjunctive wire of a powerful apparatus, the needle will stand right across the wire in all relative positions of the wire and needle; supposing the centre of the needle carried round the wire, this direction across the wire is such, that the marked and unmarked ends of the needle (198) are always in a constant position relative to the poles of the battery.

Exp. 24. Let the positive end of the battery be on the right hand of the observer, and the needle below the wire, as indicated in fig. 69 (200). Complete the circuit Z P N C, the marked end of the needle will come towards him, and the needle will stand across the wire, as represented in the adjoining fig. 70, in which P N is the conjoining wire, *s n* the needle, P the positive, N the negative side of the battery. It is difficult, but not impossible, to suspend the needle so as to give it free motion in all directions, whilst the force of the terrestrial magnet (198) on the needle may be neutralised by the influence of a third magnet, or otherwise rendered null by an astatic arrangement (98).

Fig. 70.

N

N

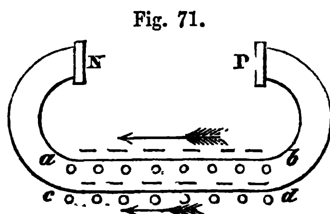
204. It is next to be observed, that, supposing the excited wire and needle to be situated as indicated in the last fig. 70 (203). Then, on moving the needle backwards and forwards, under or above the wire, so as to expose different points of the needle to the current force, the needle will be

seen to be attractive of the wire, and the wire of the needle, throughout its entire length, so that the magnetic condition of the wire is such as to attract both ends of the needle. The same result will ensue in moving the needle along under the wire longitudinally; every point of the wire will be found attractive of every point of the needle, that is to say, so long as the wire and needle remain in the position indicated in fig. 70. When, however, we reverse the direction of the needle, the direction of the current remaining the same, then the needle and wire repulse each other.

205. On further examining the magnetic condition of the junction wire, we find it highly attractive of ferruginous matter, so that filings of iron or steel, when brought sufficiently near, will accumulate about it in great quantity, until the wire becomes as it were loaded with them. On breaking the contacts N C or P Z with the battery, the magnetic force instantly vanishes, and the filings drop away from the wire as if by magic. We owe this curious fact to the labours of Arago and Davy. Davy further showed that the filings which had accumulated on the *opposite* sides of two similar junction wires similarly affected by the current were attractive of each other, whilst those on the same side repulsed each other. Such wires, therefore, had conveyed to the filings opposite polarities (196).

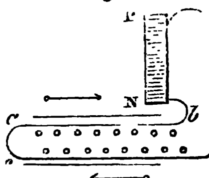
Exp. 25. Let P N fig. 71 be the terminating plates of the battery, and *a b c d* straight and parallel portions of two wires joining them; we have then two parallel currents in the same direction, as indicated by the arrows. Let the small circles and short straight lines be supposed to represent ferruginous filings collected about these wires; those on similar sides of them, being distinguished by small circles and short lines. Then the filings on oppo-

Fig. 71.



site relative sides of the two wires attract, whilst those on the same relative sides of each wire repel; thus, the filings indicated by the small circles attract those indicated by the short lines. The repulsive force may be observed by the arrangement indicated fig. 72, in which *a b* and *c d* are parallel portions of a single wire joining the poles P N, and bent so as to reverse the direction of the current in the straight portion *a b*, which amounts to the same thing as opposing the similar sides of the wires *a b* and *c d* in the last fig. 70. Davy, to whom we are indebted for this experiment, employed occasionally two separate batteries. The result had been anticipated by the justly celebrated French philosopher, Ampere, who found that when two parallel wires, *a b c d*, fig. 71, carrying an electrical current in the same direction, were free to move, the wires were attractive of each other, but repulsed each other when the currents were in different directions, as in fig. 72.

Fig. 72.



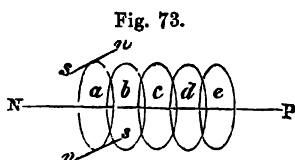
206. The magnetic force developed in a wire joining the poles of the voltaic series is common to all the metals, and their electro-magnetic condition is such, that when exposed to the poles of a common artificial magnet, they are immediately attracted or repelled by it.

Exp. 26. Suppose, in the last fig. 72, that the circuit P *d c a b* N were free to move upon the points P N. Then the marked end of an artificial magnetic bar attracts *a b* and repells *c d*, that is to say, attraction ensues when the current is moving from P to N in direction *a b*; the positive side of the battery being on the right hand, and repulsion when moving in direction *c d*, which is the same thing as bringing the positive pole P to the left hand. If small cylinders of metallic wire be placed across two fine knife edges connected with the opposite poles of a voltaic battery, the positive side of the battery being on our right hand, these cylinders may

be made to roll along on the knife edges by the attractive or repellent forces brought into play on presenting to them the marked or unmarked extremity of a magnetic bar. If the marked end be presented to the wires, attraction will result; if the unmarked end, repulsion. The forces may be reversed by changing the end of the magnetic bar, or reversing the current.

207. Upon a rigorous investigation of the relative forces of electricity and magnetism thus called into operation, it has been found that when an electrical current is caused to flow progressively through a metallic wire, the wire is everywhere surrounded by curves of magnetism placed in planes perpendicular to the direction of the current. Thus, if P N fig. 73 be the wire carrying the current, *a b c d*, &c., will be the curves of magnetism, and small magnetic needles, free to move, will arrange themselves as tangents to these curves. Thus two small needles, *n s* and *s n*, will arrange themselves as tangents to any given points of the curve to which they are applied; and if carried round the curve, would indicate circular motion round the axial wire. Hence the magnetic force emanating from the wire does not act in a line parallel to the current, but is exerted in a plane perpendicular to the wire.

Fig. 73.



Thus if P N fig. 74 be a rheophoric conjunctive wire, *a b c d* will be a circular magnetic plane, and the direction of the action will be determined by the direction of the current. If we refer the conducting wire P N to the vertical, and suppose a descending current, the direction of the action will be from left to right, that is, in the direction of the hands of a watch placed horizontally, the dial-

Fig. 74.

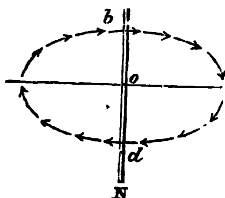
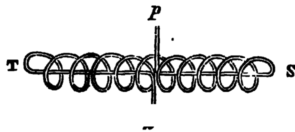


plate being next the positive pole P, and the wire P N being supposed to pass through the centre *o*.

208. This magnetic condition appears to obtain whenever concentrated electricity is passed through space. Davy found that the discharge of about 17 square feet of coated glass through air, magnetised a needle placed transversely to the explosion; and when discharged through a silver wire of the 1-20th of an inch in diameter, bars of steel 2 inches in length, and 1-20th to the 1-10th of an inch thick, were made sufficiently magnetic to attract steel needles; and this magnetic influence of the discharge extended round the wire at a distance of 5 inches, and was exerted through water, glass, or metal electrically insulated.*

209. Professor Œrsted, in announcing his great discovery, had undoubtedly some idea very analogous to this kind of action. He conceived that, in the case of the conjunctive wire, "the direction followed by the electrical powers is not a right line, but a spiral turning from the left hand to the right," an idea but little countenanced at the time by the scientific world. Ampere, however, subsequently adopted a view of electro-magnetic force involving a very similar condition. He assumed that common magnets were only masses of matter having electrical currents circulating in closed curves about their axes, upon which theory, he was led to construct an helical coil such as represented in the annexed fig. 75, in which the extremities *p n* of the wire were returned through the helix, and brought out at the centre: the one, *p*, above; the other, *n*, below. This apparatus, when so suspended as to be free to move upon the points *p n* at the time of its connection through *p n* with the opposite poles of the voltaic apparatus, takes up a position in the direction of

Fig. 75.

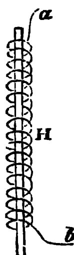


* Phil. Trans. for 1821, p. 13.

the magnetic meridian, and is perfectly obedient to the common laws of magnetism; either extremity T S being attractive of one end of a magnetic bar, and repulsive of the other, just as a common magnetic needle would be (196).

210. It may be inferred, upon this hypothesis, that ferruginous matter, such as iron or steel, would become powerfully magnetic if placed within a helix transmitting the electrical current; and such is really the case: when a steel cylindrical rod, H, fig. 76, is surrounded by an helical coil *a b*, the convolutions of which are well insulated by a varnished covering of silk thread, and a powerful electrical current transmitted through the coil, the rod receives an extraordinary degree of magnetic power, so great as not unfrequently to become magnetised to saturation. The position of the poles of a steel bar or needle rendered magnetic in this way will depend on the helix, or direction of the current. If a right helix be used, that is if the convolutions proceed from the right hand downward toward the left hand, that end of the bar or needle toward the negative side of the battery becomes the marked end (156), and if suspended will turn toward the north pole of the earth; whilst the extremity of the bar next the negative pole of the battery becomes an unmarked end and turns toward the south. The reverse takes place with a left helix. This direction and constancy of the poles may be easily inferred to be a direct consequence of the invariable position of the needle in respect of the conjunctive wire as indicated (207) fig. 73; since in comparing a small portion of each coil of the helix, fig. 76, with the contained needle, the needle will in fact be found crossed by as many conjunctive wires carrying electrical currents.

Fig. 76.



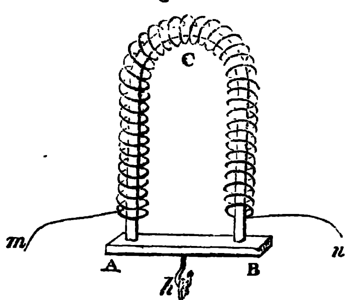
211. When iron or steel is exposed in this way to the operation of many helical coils, superposed one upon the other, the magnetic force developed seems to be almost indefinitely great, especially in very pure soft iron. In this,

however, the magnetism vanishes, or nearly so, directly we break the contact of the helix with the battery. Magnets of this description, therefore, have been considered and called more especially electro-magnets: whilst the current is in operation the force far exceeds anything which can be obtained by common magnetised steel, and we have the additional advantage of being enabled to regulate the force or reverse the poles at pleasure, either by varying the force of the battery or the extent of the helical coil, or by changing the direction of the current.

212. The most powerful electro-magnets as yet produced have been constructed of bars or rods of soft iron bent into the horse-shoe form, and surrounded by coils of copper wire covered with varnished cotton or silk thread, so as to effectually insulate the coils, and compel the current electricity to traverse the whole length of the wire. When the extremities of the helical coils are connected with the opposite electrodes of the voltaic apparatus, a degree of magnetic power becomes developed in the iron with about ten cells of a Grove's battery, sufficient to suspend a ton weight, through the intervention of an iron bar placed across the projecting ends of this electro-magnet.

The annexed figure 77 represents the electro-magnet as thus constructed, in which A C B is a bar or cylinder of very soft iron, about 2 feet in length and 2 inches in diameter, bent into a curvilinear form as shown in the figure; *m* C *n* is meant for superposed helical coils of copper bell-wire, prepared as above described, and surrounding the iron, each coil being about 60 feet in length.

Fig. 77.

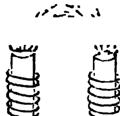


A B is a bar of soft iron ground flat to the surfaces of the

projecting ends, A B, of the iron rod, and is furnished with a hook at *h*, for suspending weights of any required amount. When the extremities *m n* of the coils are connected with a powerful voltaic apparatus, the attractive force of the extremities or poles of the magnet upon the iron bar, A B, is such, that above 2000 lb. weight has been suspended from *h* without breaking the contact.

213. An electro-magnet of this kind, constructed by Faraday, and turned with its projecting ends upward, could seize upon iron spike-nails, when projected over them, and so unite them by magnetic-inductive force, one with the other, as to form a sort of plastic mass of ferruginous matter from pole to pole, as indicated in the annexed fig. 78, and which might be swayed to and fro by the hand; either pole, A B, fig. 77, of this magnet could sustain half a hundred weight, when applied to it. The soft iron core of this magnet was 28 inches in length, and 2·5 inches in diameter. The helix consisted of copper wire about the 1-6th of an inch in diameter and 500 feet in length. This helix was disposed round the iron in four superposed coils connected end to end, so that the current traversed the whole length of the wire.

Fig. 78.



214. These astounding magnetic effects of the voltaic apparatus are necessarily of the deepest physical interest, seeing that an unknown and mysterious power of nature has been called up into active operation, which, from the earliest periods of philosophical history, has been the wonder and admiration of each succeeding age; and also that much light has been thrown upon the probable source of the magic influence of this power in directing the position of the mariner's needle, and aggregating into masses disjointed particles of ferruginous matter. It would be without the limits of a rudimentary work such as this, were we to enter upon all the phenomena incidental to the actions and reactions of rheophoric wires and magnetised iron or steel upon each

other, and the numerous motions and effects to which they give rise. Such phenomena come more especially under the beautiful departments of science termed "electro-magnetism" and "magneto-electricity." The experiments and phenomena to which we have called attention, are probably sufficiently illustrative of the magnetic powers of the voltaic pile, the great object we had in view, and to which our attention has been necessarily restricted. We must therefore be content with a simple notice of a few of the more elementary results of electro-magnetic and magneto-electric inquiries.

215. First, we have to observe, that when a conjunctive wire (200) is free to move under an appropriate mechanical arrangement, it will revolve about the poles of an artificial magnet (195); conversely the magnet will revolve about the wire: if both are free to move, they will revolve round each other.

Secondly, a conjunctive wire may be so disposed as to become under the control of the great terrestrial magnet (198), and obey all the laws referable to terrestial magnetism; taking the magnetic dip or inclination (197) just as the ordinary balanced needle would do.

Thirdly, an artificial magnet, mounted on vertical pivots, and transmitting under the form of a conjunctive wire an electrical current from its centre to either end, or conversely, will revolve upon its vertical axis with great rapidity.

Fourthly, two conjunctive wires, free to move, repulse each other when the currents are in opposite directions, and attract each other when in the same direction.

Fifthly, it has been found that not only does electrical-current force originate pure magnetic force, but that, conversely, pure magnetic force originates electrical-current force, giving rise to a series of effects of the very first importance. By means of common magnets, electrical currents become developed in metallic bodies, especially when aided by helical coils, and of such power as to produce electrical sparks, and shocks, and otherwise exhibit all the

phenomena of the ordinary electrical machine and voltaic apparatus. Metals beaten into thin metallic leaves may be deflagrated, fine metallic wires made white hot. Electro-chemical decomposition effected, and a variety of other effects produced. This property of ordinary magnets to induce electrical currents without the aid of any voltaic circle, has been termed "magneto-electric induction."

216. We can scarcely conclude this branch of our subject to which this chapter has been devoted, without a brief allusion to some late forms of apparatus dependent on electro-dynamic and magneto-electrical induction, and which, through the operation of secondary currents, have been found to develop ordinary electrical powers of a most surprising character.

217. When a wire is under the influence of the current force of the voltaic apparatus, the current appears to exert upon the electricity of conducting matter within the sphere of its influence a peculiar inductive effect, and in such way as to put the electricity of the near matter in motion if previously at rest, or, if in motion, either to increase or diminish the current force. This effect, termed volta-electrical induction, is however of a momentary or temporary character, and is only evident at the instant of completing or breaking the circuit. It may be easily apprehended by reference to the following experiment:—

Exp. 30. Construct two long adjoining helical coils, (*a n m b*, *c n m d*), fig. 79, each coil consisting of about 250 feet of copper wire covered with insulating thread; let the two coils be wound together upon the same cylindrical hollow mould *m n*, so as to go on side by side, and be superposed upon each other, as indicated in the figure; connect the extremities

Fig. 79.

a b of one of the coils *a n m b*, which we will call the secondary coil, with a delicate electro-magnetic multiplier or rheoscope *a b* (98), and the extremities *c d* of the other coil *c n m d*, which we will call the primary coil, with the opposite extremities of a Wollaston's battery of about 100 pairs of plates (72), complete the contact with the battery through the coil *c n m d*, and the rheoscope *a b* will become deflected in a given direction by the volta-electrical induction upon the coil *a n m b*; the effect will be, however, like a passing wave, it will be only for the instant, after a few vibrations the rheoscope will again recover its first position. Proceed now to break the contact with the battery through the coil *c n m d*, then another temporary wave will ensue, and the galvanometer needle will be deflected for a moment in the opposite direction. On examining these two different deflections of the rheoscope needle *a b*, we find that the current induced in the secondary coil on making contact is in the opposite direction to that of the primary current in the coil *c n m d*, whereas, on breaking the contact, it is in the same direction.

218. This inductive effect may either occur on a secondary wire, or it may take place in the primary wire; that is to say, the primary wire may induce a current in itself on making or breaking contact with the battery: hence, the spark observed to take place at the point of disruption is much greater in a long wire or helix than in a short wire. If the wire connecting the electrodes of the battery be short, say about a foot only in length, the spark observed on making or breaking the contact with the battery is comparatively feeble, occasionally insensible, — it is, in fact, dependent entirely on pure electrical action; but if a wire of 50 feet be employed, then this volta-electrical induction comes into play, and the electrical spark is considerable. It is still more increased when the 50 feet of wire are wound into an helical coil, in which case there is a reciprocal inductive action between the spiral turns of the coil.

219. Volta-electric induction may be designated as a lateral action of the primary current upon the electricity of the surrounding or next particles of conducting matter, and it takes place in planes, perpendicular to the respective points of current force. The effect is probably identical with the curves of magnetic force (207) fig. 73, or is intimately associated with them.

220. When a soft iron rod is introduced into the helical coil, at *m*, (217) fig. 79, then, as first observed by Mr. Jenkin, in experimenting with the helical coil of the electro-magnet, (212) fig. 77, this volta-electrical inductive effect becomes amazingly increased; if we grasp the ends of the secondary wire through metallic cylinders, and make or break the contact with the battery, through the animal frame, then a smart shock is immediately felt; and is of such a nature as to be, with powerful arrangements of the apparatus, quite insupportable. Bright vivid sparks may be obtained from the secondary wire, and an amount of ordinary electricity developed, quite unprecedented. We, in fact, combine the effects of electro-dynamic with magneto-electrical induction; since at the moment the iron loses its magnetism on breaking the contact with the battery, the secondary wave becomes increased in force.

221. The currents thus produced in the secondary wire may, by appropriate arrangements, be interrupted through the intervention of some thin insulating substance; we may hence manage to stop off, as it were, the first currents in the one direction, due to the instant of *completing* the battery contact, and preserve those only due to the *breaking* of the battery contact, found to be the most energetic; a rapid series of intermitting sparks in one direction is the consequence. The intensity of this secondary current is such as to pass through half an inch of air, whilst the inducing current on the primary wire is so feeble as to be scarcely appreciable through a very small distance.

222. A very powerful arrangement of these primary and secondary wires was resorted to by Mr. Hearder, some years since, under the form of a medical instrument, for the application of voltaic electricity in cases of disease, for which he received the silver medal of the Royal Polytechnic Society of Cornwall. Other powerful and valuable forms of the coil-machine have been produced by Bird, Henley, and the Rev. F. Lockey, highly deserving attention. More recently a volta-electric-inductive apparatus has been produced by Ruhmkorff, of still greater power, and which bids fair to prove of vast importance in the further investigation of this department of physics. Hearder's form of the electro-dynamic and magneto-electric-induction machine is represented in the annexed figs. 80 and 81.

Fig. 80.

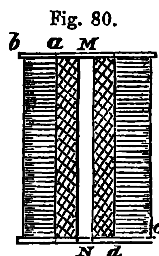


Fig. 80 represents the arrangement in section, M N is the soft iron core within the helix, generally consisting of a bundle of soft iron wires; *a d* is the primary coil, and *b c* the secondary coil outside it.

Fig. 81.

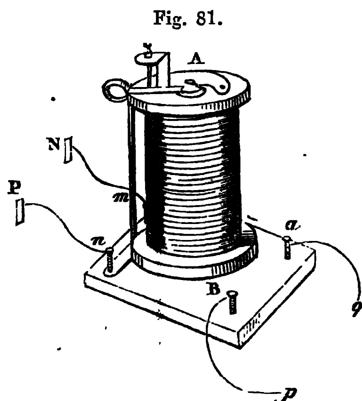


Fig. 81 represents the instrument as complete. In this figure, A *m* B is the general cylindrical mass, consisting of the primary and secondary coils, just described, fig. 80, with the hollow cylindrical mould, and its interior soft iron core; *m n* are the terminations of the internal primary coil next the core A to be connected with the positive and negative sides P N of the battery; *a* B are the terminations of the external or secondary

coil, from the extremities *p q* of which the effects of the induced current are apparent. There is a small automatical or self-acting rheotomic apparatus at A (107) by which the contacts with the battery are rapidly broken and renewed, and the current determined in a given direction between *p* and *q*. This rheotome depends on the attractive force of a small piece of soft iron and the iron core, when made electro-magnetic by the action of the current (210), being thus lifted, the contact with the battery is broken. The iron core at this instant loses its magnetism, and hence ceases to attract, so that the iron now falls back again by a spring action, and in doing so re-makes the contact as before; the rapidity of this movement is wonderful. The wire *a d*, fig. 80, of the primary coil, is a stout copper wire, covered with thread, of moderate length, being about 150 feet; the wire *b c*, of the secondary coil, is a finer wire of covered copper, of about 2100 feet in length, or 14 times the length of the primary coil. It has been found desirable to employ a comparatively short length of stout wire for the primary coil, and a great length of fine wire for the secondary. Gassiot constructed a coil of this description, in which the secondary circuit is said to have been 12 miles in length.

223. In the medical coil of Hearder great care has been taken in the proportioning the length and thickness, and consequently resistance, of the primary coil to the electromotive power of the battery, by which means smaller batteries than have been hiterto used are made available. With a small Smee's battery (79) the electrical effects of this apparatus are quite surprising. Strong electrical sparks are produced, and a striking distance obtained of several inches, through rarefied air, small Leyden jars may be charged, and metallic leaves deflagrated. A remarkable phenomenon is observable in this instrument: when the terminations *p q*, fig. 81, of the secondary wire are joined, we have as usual a severe shock; but if whilst one finger

touches the terminal *a*, we bring another finger of the same hand to touch the terminal B, then we obtain pungent sparks without a shock.

224. In Ruhmkorff's apparatus—the latest and most powerful of these contrivances; known by the especial designation of Ruhmkorff's coil—great attention has been given to the perfect insulation of the wires forming the primary and secondary coils. The apparatus has a rheotrope (108) attached to it, by which the current in the primary wire can be reversed. The electrical discharges of this coil are quite frightful, and the light disengaged by them in an exhausted receiver, very magnificent and remarkable. The Leyden battery is easily charged by it up to a certain intensity, and common electrometers powerfully affected thereby, showing as in Hearder's apparatus a conversion of the dynamic force of the primary current into the static force of the electricity of induction. Grove, on connecting the terminals of the secondary wire with the coatings of a Leyden jar, produced, by means of a Lane's electrometer, a series of rattling discharges quite appalling. When, however, the jar is not thus intervened the discharges are soft and flame-like, as in discharges of common electricity from the Leyden battery through water. This flame-like effect, as in the case of the Leyden discharge through water, can readily ignite gunpowder and other inflammable matter, whilst the rattling discharge fails to do so, probably from its mere expansive violence.

225. It may be perhaps not unimportant to remark in reference to the theory of volta-electrical induction (217) commonly employed in explanation of secondary currents, that, as observed by Hearder, a great question still arises as to the real source of these currents, whether in fact they may not depend altogether on the temporary magnetic state induced in the soft iron placed within the helix (220), which in its turn reacts upon the secondary wire in a way converse to that of the electro-magnetic action of the primary

current. The primary current first develops magnetism, and then the magnetism develops electricity through the secondary wire, being the converse of the electro-magnetic action before adverted to (207), fig. 73. Whether in fact the feeble inductive effect observed by Faraday in approximating a wire transmitting a current toward another wire in a quiescent state,* may not result from the small amount of magnetism induced in the primary wire (205). It would appear from some extensive experimental inquiries by Mr. Sjorth, a Danish philosopher, lately resident in Liverpool, that powerful electrical currents may be induced in the secondary coils of the apparatus just described (222), merely by the influence of artificial magnets on the bundle of soft iron wires within the helix, without the aid of any primary current or coil whatever. Mr. Henley has in fact already applied this principle to the purpose of a magneto-electrical telegraph; so far this question may probably be a fruitful source of new discoveries in this branch of voltaic electricity.

* Expt. researches (18).

CHAPTER VIII.

Concluding Remarks—The question of an Animal Electricity further considered—Grounds for supposing that Animal Life is more or less associated with Electro-motive or Current Force—Discoveries of Nobili and Matteucci—Electrical Organs of the Torpedo and Gymnotus—Researches of M. du Bois Reymond—Application of the Voltaic Apparatus to practical purposes briefly noticed.

226. ALTHOUGH the researches of Volta, and his fine discovery of the galvanic pile were quite conclusive as to the cause of the spasmodic and other muscular contractions observed by Galvani to occur in the limbs of a recently dissected frog when exposed to the influence of metallic electricity (4), still the great question of an inherent vital electricity in animals, and other organised living structures, demands especial investigation. The source of animal life, and the actual nature of what we term the vital principle, is doubtless one of those mysterious and wondrous operations of nature in all probability past human comprehension. It is however permitted to us to pursue a line of approximative research, which may at least enable us to better appreciate the phenomena of this truly awful element of existence, or at least the agencies through which its operations are made manifest.

The more recent discoveries in voltaic electricity, the nature and laws of what we have termed current progressive force (24), to say nothing of the great perfection of delicate instruments by which such forces may be traced and estimated, and the least possible amount of galvanic action detected, would necessarily tend to resuscitate the long dormant question of an "animal electricity," although under a form differing in some degree from that propounded by Galvani (5).

227. Philosophers from the earliest periods of electrical

discovery, appear to have entertained somewhat vague speculations, of a very general character, as to the electrical origin of the vital principle: the brain and nervous system, as may be readily imagined, would be referred to as the more immediate material organs through which physical is linked to metaphysical existence; and that too by the circulation of an hypothetical element, termed the "nervous fluid," employed in giving vitality to every part of the animal frame. The electrical powers of the torpedo, and other fish (1), have been quoted as collateral evidence of the existence of such a principle of animal life, and of its being no other than the electrical agency itself; an idea further countenanced by the experiments and views of Galvani; moreover, in the gymnotus and torpedo, and other electrical fish, we observe a voluntary power of originating progressive current force, through a series of organs similar in their physical character to that of the voltaic circle, or of the voltaic pile. So far, therefore, the notion that there may exist in the animal economy a power of determining, or otherwise of originating, electrical current power through nervous and muscular structure, and thereby supplying a kind of vital stimulus to the various parts of the animal frame, may be conceived to obtain some little countenance. Whatever may be the nature of the link which ties together in some way nervous power and current action, it is clear that the electrical functions of the torpedo and gymnotus show the disengagement of electricity by a nervous current; as observed by Faraday, we here see nervous power transformed into electrical force.

228. The brain and spinal cord, as just observed, would necessarily be the material organs referred to as the source of this power, the brain, more especially in the human race and higher orders of animals, would be the great active centre of such a power. Accordingly, many profound writers * have ventured on considering the brain as an electrical pile constantly in action, which may be

* Herschell's Discourse: Dr. Arnott's Elements of Physics.

conceived to discharge itself at regular intervals, whenever the tension of what may be viewed as its charge surpassed a certain point, as in the case of the electrical unit jar;* then, supposing that at each discharge a given amount of vital stimulus became transmitted as current force through the nerves, there might arise all the vast variety of physiological effects observable in the animal economy: the heart, for example, might be kept continually pulsating, as in the vibrating pendulum of the electrical column (49), fig. 20. Various secretions might arise out of decomposition, recomposition, and transfer, as already explained in treating of the chemical effects of the pile (137), Chap. V., and other vital operations effected requisite to physical existence. Benoît Mojon has endeavoured to show experimentally, that the different animal fluids are separated from the glandular system by means of an electrical agency existing either in the glands themselves, or in the blood which flows through them, and the nerves with which they are furnished. Further, we may conceive the operation of a species of electrical inductive force,† to extend to dynamical as well as statical electricity, thus giving origin to an especial class of sympathetic affections between one organised animal system and another; and in this way bringing about many of those extraordinary effects so strongly insisted on by those who maintain the existence of Mesmeric influences, as also of other effects peculiar to the many curious aberrations in the nervous system so frequently alluded to in our medical journals. Although we should undoubtedly be very cautious of these hypothetical speculations, more especially in a field in which the imagination has such an unlimited room to rove, yet, under the due restraint of observation and experiment, such speculations may not eventually be altogether unprofitable; and we should wisely remember, in giving attention

* Rudimentary Electricity (93), p. 105.

† Rudimentary Electricity (20), p. 15.

to a well authenticated statement of extraordinary and remarkable phenomena of animal life, that there are "many things in heaven and earth little dreamt of in our philosophy." It is worthy of remark, that almost every cultitivator of this department of science has been impressed with the notion, that electromotive force is an element of animal life, and that this power is closely associated with the brain, the spinal cord, and the nervous system.

229. Much light has been recently thrown upon the question of animal current force, and the existence of what may be called an animal electricity, by the beautiful and interesting researches of Nobili, Matteucci, and Du Bois Reymond. Animal electricity had quite disappeared as a recognised branch of science for nearly a quarter of a century, when Nobili, in 1827, detected a current action in the frog capable of deflecting the magnetic needle (96). When the spinal column of a frog is made to touch a solution of salt contained in a glass cup, and the feet immersed at the same time in a similar solution, contained in a second cup, the limbs are observed to contract immediately; the two cups are connected by moistened cotton, as in Exp. 20 (159), fig. 63. If an extremely delicate rheoscope (100) be included in the circuit, the needle becomes deflected, and in such way as to indicate a current from the feet to the head of the animal; that is, from the muscle to the nerve. This current has been more especially designated by the term, "frog current." It appears by Nobili's researches to be permanent; that is, it maintains a constant deflection of the rheoscope in a closed circuit (96); the action is increased when several frogs are included in the battery arrangement.

230. Matteucci, considering that both heat and light are evolved in the organisation of living animals, through the agency of certain chemical actions, thought it would be a sort of physical anomaly, if electricity were not also evolved under conditions favourable to its development. The

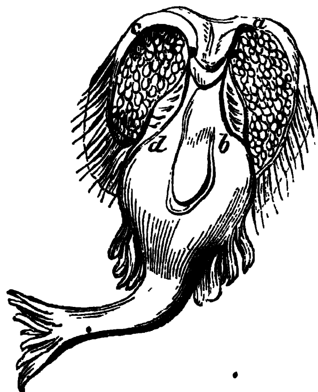
following easy experiment, resorted to by this celebrated physiologist, proves the existence of an electrical current at the instant of connecting two different portions of an exposed muscular portion of a living animal.

Exp. 37. Having made an incision in the pectoral muscle of a pigeon, and carefully removed the integuments, introduce a filament of the nerve of the rheoscopic frog (67) into the bottom of the incision, and let another filament touch the surface of the muscle; the muscles of the frog immediately evince the presence of an electrical current through the nerves. Matteucci calls this a muscular current, it is observable in all animals, and is sensible to the galvanometer when delicately constructed. This current is also producible by means of a muscular pile made up of muscular portions of the lower limbs of the frog, or the muscles of other animals of different classes; this muscular current is found to be more feeble in the muscles of animals elevated in the scale of beings. Frogs and fish evince the presence of a current several hours after death, but in the mammalia and birds no current arises a few moments after life is extinct. The source of this current has been referred to the chemical action of the nutrition existing in the muscle; the blood, charged with oxygen, in contact with the fibre, constitute the elements of a pile, and correspond with the acid solution and zinc of the ordinary apparatus.

231. It may not perhaps be undesirable to refer here more especially than has been hitherto done, to the electrical organisation of the torpedo, and other of the electrical fish. We have already seen (1), that the two opposite surfaces of the body of the torpedo are the electrodes or poles of the electrical organs with which this animal is furnished, so that the greatest shock arises on touching the back and belly of the fish. The rheoscopic limb of the frog (67), placed on the body of the torpedo, evinces powerful contractions at each shock, and will even do so at some considerable distance, provided the fish be placed on a wet

cloth, evidently showing, as in Galvani's original observation (5), the presence of electricity. The direction of the current, which thus gives origin to the numbing sensation experienced on touching the torpedo, is from the back to the belly of the fish, and proceeds from two peculiar organs found on each side of the head and gills, extending to the great fin and cartilage below the thorax or chest. These organs are composed of several hundred prismatic masses, set closely together like millet-seed, and consist of small hexagonal or pentagonal columns placed side by side; the entire organ resembles the cells of a honeycomb; the columns are arranged vertically, and are supplied with a profuse ramification of large nerves. The honeycomb cells are filled with a dense fluid, consisting of water, albumen, and a small portion of common salt. Volta considered this structure as a perfect electromotive pile, which the animal rendered active at will, by compressing the columnar structure, and establishing contacts with the fluid of the apparatus and the skin. The annexed diagram (fig. 82) will serve to convey some notion of the torpedo. In this diagram *a b* and *c d* are the exposed electrical organs.

Fig. 82.



232. The shocks produced by these organs appear to be under the control of the animal, through the medium of a certain portion of the brain. If we touch some portions of the brain, no shock ensues; but there is one portion, termed by Matteucci the "electrical lobe," which on being touched excites the electrical organs, and affects them either on the right or left side, according with the corresponding

side of the lobe touched. We may remove all the other lobes of the brain without disturbance of the electrical functions; but if this fourth lobe be torn or destroyed, then the numbing power of this wonderful fish is no longer apparent. The annexed fig. 83 is a diagram of the brain of the torpedo, in which C is the cerebrum, O the optic lobes, R the cerebellum, and E the fourth or electrical lobe, upon which the power of the fish is dependent.

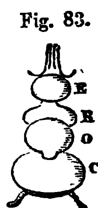


Fig. 83.

233. Almost the whole of the gymnotus (2) is organ. The vital parts of the fish, that is to say all the viscera, being packed close behind the head. The upper part of the rest of the body consists of back bone and muscles, below which, extending for about two-thirds of the diameter of and the body, is the numbing apparatus; this consists of two pairs of cellular columns—one pair on each side—a larger and smaller, they are placed one over the other. The small animal portion of the fish is so contrived as to support and sustain this great electrical organ; the cellular structure of which it consists is simple, being a series of long septa or flat partition membranes, crossed by thin membranous plates, there is a regular series of these transverse plates extending from end to end between the longitudinal septa; Hunter counted no less than 240 to the inch, so that what may be considered as the electrical surface is vastly multiplied. The organs diminish toward the tail of the fish, and constitute an extremely powerful apparatus for offensive or defensive purposes. About five kinds of these electrical fish have been discovered; and a species of electrical organ has been further detected by Dr. Stark in the tail of the common skate.* The following fig. 84, which is also a mere diagram, may be useful in affording some notion of the structure of the gymnotus, as just described. In this diagram the small portion N represents the head and body of the fish; *a* is the small and *b* the large electrical

* Edinb. Phil. Journal, July, 1855.

organ of one side, placed one over the other, and extending from the head downward to the tail.

Fig. 84.



234. It would appear then, from these facts, that although no immediate and direct electrical organs, such as we have described, have been found in the higher orders of animals, yet it is not impossible but that other kinds of organised structures possessed by them, may be susceptible of electrical excitation of a modified kind, of vast influence in the animal economy; and we have yet to learn, how far the many wonderful impressions made by various feelings of the mind upon the whole animal frame may not originate, and be propagated through, the medium of the brain and the nervous system, either by voluntary or involuntary action, much in the same way as the electrical lobe of the brain of the torpedo gives energy to its electrical organs. According to Mr. A. Smee, F.R.S., who has recently published an interesting, although somewhat speculative work relative to this subject, man is a mere bundle of voltaic mechanism. What we term life is virtually a series of changes of various kinds and forms in the matter of which he consists—such, for example, as nutrition, assimilation, growth, reception of impressions, together with the action of the senses, of memory, reason, thought, &c. Life is no independent reality, apart from organisation. We have here to study forms of voltaic combination consisting of membranes and fluids. In animals we trace the existence of a central and peripheral parenchyma supplied with bright arterial blood, and a connection between the two composed of nervous fibre. The central parenchyma constitutes the brain in the higher animals, and the ganglia in the lower. The peripheral parenchyma comprise the organs of sensation and

motion. By this apparatus we receive impressions from the external world, and transmit them to the brain which registers and combines them.*

235. We are indebted to M. Du Bois Reymond for a large amount of new and valuable information relative to this most interesting question, of what may be termed electrical vitality. This philosopher having observed that the rheoscopic limb of the prepared frog (67) is only affected at the instant of making or breaking the current force, was led to infer that the muscular contractions depend more immediately on variations in the strength of the current; under currents of uniform force the animal fibre is tranquil, hence the excitation of the motor nerves depends on variations in the current power from one instant to another—the excitation being greater the more rapidly or suddenly such variations take place. *Sensient* nerves, on the contrary, are not only affected by changes in the current, but continue to be affected during its continuance. M. Du Bois Reymond has shown, by a delicate and capital series of experiments, that the frog current (230), is really identical with a muscular current common to the muscles of all animals, and which he has made evident through the instrumentality of his beautiful rheoscope (100). When contacts are made with different points of portions of the muscles of recently-killed animals, the needle almost invariably indicates the presence of current electrical force, more especially when the instrument is under the influence of contact with a transverse and longitudinal section of a muscle. Similar results ensue when transverse and longitudinal portions of a nerve are brought to operate upon the rheoscope in a similar way.

236. It has been inferred from these very delicate and beautiful experimental researches, that the brain, spinal cord, and nerves, together with the muscles of animals generally, are all endowed with electromotive power; the longitudinal sections of the muscles and nerves being

* Elements of Electro-Biology.

positive, and the transverse sections negative; that the currents thus artificially observed, are to be considered only as portions of more intense currents circulating in the interior of the general muscular and nervous system of the animal.

237. Although M. Du Bois Reymond's investigations are most fully entitled to the confidence of the scientific world, from the surprising skill and care with which his experiments have been conducted, yet the student should understand that nothing short of a similar perfect manipulation will enable him to pursue experimentally this very interesting and exciting question relative to the connection subsisting between vitality and electromotive power.

In the employment of the rheoscope (100), the electrodes leading to the coil should consist of plates of platinum, and it is further essential that these plates be perfectly homogeneous, the least difference in them will alone cause current force sufficient to influence the needle, so that we require to be as much on our guard in such experiments against deception as in the use of the electrical condenser and doubler (66). The precautions of M. Du Bois Reymond to avoid errors in his experiments were almost unlimited. The platinum plates were first cleansed with alcohol and sulphuric ether; then they were washed clean in nitro-muriatic acid, then in distilled water, lastly they were heated to incandescence.

238. His mode of using the rheoscope is as follows:—Platinum plates duly prepared being placed in communication with each extremity of the coil, are covered with blotting-paper up to the intended line of immersion, and plunged *simultaneously* into opposite vessels of porcelain or glass, filled with a saturated solution of common salt, the circuit is completed between these vessels through the medium of cushions made of fine layers of blotting-paper saturated with the salt solution; these cushions rest upon the edges of the glass vessels, and also upon little blocks of wood within;

the portion of muscular fibre, or other animal part, the subject of experiment, is placed between these cushions which project a little beyond the glass.*

239. Such appears to be the present and more recent state of the question of animal electricity as compared with the views first entertained; and which certainly entitle it to high consideration as a branch of experimental science upon other theoretical grounds than those so summarily disposed of by the experiments and researches of Volta.

240. Having thus far discussed and explained the general phenomena of galvanic and voltaic electricity, and traced the march of this most important branch of physics from the time of its earliest history to the present day, it now only remains to advert briefly to some of those astonishing applications of its principles to the great practical purposes of civilised life. The first to be noticed, and certainly the most astounding in extent, is the application of current magnetic force (194) in the transmission of information and thought, through almost unlimited distance, and by which the most remote portions of our globe are likely to become placed, as it were, in speaking communication with each other. This application of current force to telegraphic communication rests, as may be at once perceived, on the general principles and phenomena treated of in Chapter VII. Electro-magnetic currents transmitted between the opposite poles of the pile through conjunctive wires of enormous extent, are employed to deflect magnetic needles at a distance of hundreds of miles, so as to be available as alphabetical signals determinable by the direction in which the needles are deflected (200). By a rheotomic arrangement (106), the actual letters of the alphabet may be brought under the eye of a person, from almost any distance, and the transmitted communication at once printed off and recorded.

* The reader will find a minute description of the whole process of manipulation, in a valuable little work by H. Bence Jones, M.D., F.R.S., &c.

Such is the extent to which this practical application of the power of the pile is now being carried out, that telegraphic submarine cables are laid down and in successful operation across various straits and seas, and will, in all probability, ere long, traverse the bed of the great Atlantic from the west coast of Ireland to the mouth of the St. Lawrence. These conjunctive wires are seen stretched between standard posts along our lines of railway, and are, of course, familiar to every traveller. They extend from station to station between the poles of voltaic batteries in each, and are so arranged as to admit of the current passing forward and backward between any required points. It is only requisite, as may be inferred from the phenomena of the circuit (96), that the line of conduction be complete in all its parts, so that the current may be enabled to set out, as it were, from one pole of the battery, and, after circulating by means of the conjunctive wire through any distant station, return to the other pole. When the wires are sustained in the air, as in the telegraphic arrangements of the railways, the return part of the circuit is effected by the agency of the ground or earth, which is found sufficiently conducting for that purpose. The voltaic batteries commonly employed in this country are for the most part such as we have described (68) (72), being common Cruickshanks' or Wollaston's Batteries, with amalgamated zinc plates. They are made active by filling the cells with fine sand, saturated with dilute sulphuric acid. The conjunctive or conducting wires are usually of iron, coated with zinc, and, as just observed, are either supported on insulating posts in the air, or otherwise encased in gutta percha, or other effectually insulating substance; and, being duly protected, are carried under ground or over the bed of the sea. The great transmarine telegraphic cables consist of bundles of conjunctive wires of enormous length, each wire being enveloped in a thick covering of gutta percha, and protected from derangement by incorporation with a stout cable of iron wire. Thus sufficient

strength is obtained to resist the operation of the mechanical forces to which such a cable, in various ways, is necessarily exposed. The public are indebted to Messrs. Newall & Co. for this fine electro-mechanical arrangement. By means of these cables, the English and Irish channels, and a great number of other straits and seas, are already successfully crossed by telegraphic communication, and there is little doubt, before many years elapse, but that Europe will be telegraphically united with the African continent through the Mediterranean islands, and eventually with India and the great American continent, so that its capital cities will receive or transmit information from one to the other, and extend their communication to the most remote parts of our globe.

The mechanical arrangements by which these several communications are finally perfected and carried out, will be found of the most interesting and beautiful description. By the rheotrope arrangement (211), the agent who transmits the signals at our railway stations can turn the current in any required direction, so as to traverse what is termed for distinction's sake the "up line" or the "down line," either to any given station, or through the entire length of the whole extent of the circuit, or he can suspend or transmit the current at given intervals of time; moreover, he can, by means of the same mechanical arrangement, set in motion an alarm apparatus, through the instrumentality of an attractive force, developed by electro-magnetic action at the given distance in soft iron, and by which the attention of persons at a given station is immediately called to the approach of signals through the magnetic needles to be deflected by the electro-magnetic multiplier in certain directions (96); being the alphabet and language in which the telegraphic message or information is virtually written.

241. It would be an ungrateful omission in any notice of electro-telegraphy, however brief, not to acknowledge the deep obligation we are under to Professor Wheatstone, F. R. S.,

through whose great exertions and fine researches and inventions at King's College, London, we mainly owe the present advanced state of this wonderful application of current force. Before a mile of telegraphic communication had been ever laid down in this country, Wheatstone had proved the possibility of transmitting signals through many miles of conjunctive wire; had shown how, by a rheotomic apparatus, any given word might be spelled by successive letters, and brought under the eye of a person at a distance, had contrived the distant alarum set in motion by electro-magnetic action, and had, in fact, developed and laid down all those great practical elements upon which telegraphic communication through the agency of the voltaic apparatus is so entirely dependent. Many other persons there are, undoubtedly entitled to a large share of public gratitude in the further prosecution of this department of practical science, as may be seen in the many ingenious mechanical arrangements of Cook and others; still, however, we are obliged to confess that the great first step in electro-telegraphy in this country originated with Wheatstone in the precincts of King's College.

242. The operation of current force in magnetising iron and other metals, and the disappearance of the induced magnetic state directly the current ceases (203), has been further applied as a source of mechanical power in the construction of electro-magnetic machines or engines. Such machines depend on a rapid change of polarity in masses of iron surrounded by spiral coils (211), by which they are caused to alternately attract and repel other electro-magnets; or otherwise by a rapid magnetising and demagnetising of iron in a similar way without any change of polarity, and by which an attractive force is brought to bear upon other masses of iron, the attraction being operative in pulling them forward, but no longer. In either case the moveable masses are fixed to the circumference of a wheel, and the wheel is so placed as to admit of the action of the force

upon the extremities of the radii, by which a rotatory motion is obtained.

243. The chemical powers of the pile (137) have been also productive of very wonderful results, more especially in their application to the arts and to the purposes of civilised life. Electro-metallurgy, comprising the processes of electrotyping, electro-plating, and gilding, is a branch of practical science of the utmost value. These processes, as may be inferred from the phenomena of metallic deposit already illustrated, (146) Exp. 18, are based upon the reduction of metals from solution by secondary action. The idea, however, of giving to the metals so reduced, a certain form and character, is of comparatively recent date, and originated with Jacobi of St. Petersburg, and Mr. Spencer of this country. We see in the operation of a Daniell's battery (76) with what rapidity copper is deposited at the cathode out of the liquid solution by which the battery is rendered active. Now, when metals are so deposited under certain conditions, the deposited metal assumes with astonishing exactitude the form of any body upon which it settles, and hence becomes moulded as it were to the given substance with so much fidelity as to become identical with it after removal. The art of thus producing copies of coins, medals, &c., in metallic deposit has been termed on the Continent "Galvanoplastic," or in this country "Electrotype." By this ingenious art, faithful copies in metal, of statues, bas-reliefs, medals, medallions, &c., are successfully obtained. Great difficulties would at first necessarily arise in the progress of such an art; very refined means of detaching the deposited metal without damage would be requisite, as also for the formation of moulds of various kinds, and the production of faithful imprints of the given subject; all these difficulties, however, have been so completely met, as to enable us to obtain in metallic relief exact imitations of the finest works of art as may be seen in almost every public museum. If, for example, we would copy a fine medal, we may impress it upon a mould

of some soft substance, such as wax, sulphur, or plaster, and then, having brushed over the mould with a little black-lead wetted with rectified spirit to render it sufficiently conducting, we proceed to immerse it in a metallic solution under the influence of the negative pole of the voltaic apparatus (162). In a short time the mould becomes covered with metal, which being allowed to deposit up to a given thickness, is removed without much difficulty, and we have the impression required. Such is one of the means employed in the application of the voltaic apparatus to this kind of metallurgy.

When, instead of the metal being removed after deposit, we desire it to remain, so as to cover the given mould with a new and permanent surface, we arrive at the valuable arts termed "electro-plating," "electro-gilding," &c., by which the inferior metals virtually acquire all the practical value of silver or gold. In this way articles of domestic use, such as tea-urns, tea-pots, &c., or otherwise baskets, branches, &c., being first formed of an inferior metal after a given pattern, may receive a surface of silver, finally constituting an article as efficient and of as much practical value as the same in entire silver. The Messrs. Elkington, of Birmingham, have been especially fortunate in perfecting this process, and have, in consequence, obtained patent rights for their methods of manipulation.

Any metal may be covered with another metal, through this wonderful agency of the voltaic apparatus, so that articles manufactured of wrought or cast iron, may receive an exterior close coating of zinc or copper,—even common cloth may be coated on one side with metal.

244. It would be foreign to the purposes of a Rudimentary Treatise such as this to enter into the details of this branch of practical science, together with all its various ramifications; we can only call attention in a summary and general way to the results arrived at, and the principles from which they are derived; we must, therefore, be content

in concluding our notice of electro-metallurgy with a brief allusion to the recent arts of "galvanography" and "electro-etching." In "galvanography," plates fit for printing from are obtained by writing with varnish on a metallic surface and then depositing copper on it, so as to cover the given lines. In "electro-etching," the design is traced on a metallic plate through an etching ground of varnish—the back of the plate is likewise covered with varnish. The plate is then immersed in what is called a decomposition cell, containing a liquid solution, which, under the influence of the voltaic battery, can act on the lines of exposed metal. Thus we may etch on iron with a solution of common salt; on silver with a solution of sulphate of silver, and so on. The experiment is so disposed, and the connections with the electrodes of the battery are such as to effect the etching at the anode, that is at the positive side of the apparatus.

245. The art of dyeing, we may further observe, has also received singular assistance from the chemical powers of the pile, as may be seen in the process of dyeing in figures upon cloth, constituting a species of electro-calico-printing. In this process, the required pattern is engraved on a metallic block, and the cloth wetted with a weak acid solution. The cloth is then placed on a sheet of tin-foil, or other conducting surface. The metallic block is now connected with the positive electrode of the apparatus, and the tinfoil with the negative electrode: directly the engraved metal-block touches the acidulated cloth, the exposed portions of its metallic surface are dissolved and incorporated with the cloth, thereby impressing on it the given pattern in metallic solution; the impressed pattern is now passed into the ordinary chemical re-agents or dyeing liquid, and we have the required colour produced. Thus if the metal be iron, and the cloth wetted with dilute muriatic acid, we have the pattern deposited in muriate of iron, which if subsequently passed into a bath of prussiate of potassa, will produce a pattern of a beautiful blue colour.

246. The heating powers of the pile (166), Chap. VI., do not appear to have been as yet successfully applied to any great practical end, except as a means of blasting rocks, or of obtaining distant explosions of inflammable matter either on land or under water. This is effected by passing an extremely fine and short piece of platinum wire through the body of the charge contained in a water-tight cartridge. When the current is caused to pass through the cartridge by any of the conjunctive wire arrangements already noticed (240), the fine wire glows with a red heat (169), and immediately sets fire to the charge.

It is by no means improbable, but that some great advance may yet attend future discoveries in the application of this power of the pile to the ordinary purposes of life. We have seen, for example (169), Exp. 26, that water may be made to boil through the instrumentality of a metallic wire passed through the vessel in which the water is contained, the wire being heated by the voltaic discharge. Steam can certainly be thus generated without the aid of common fuel, and may be the germ of some expanded process leading to vast practical consequences. The heating powers of the pile have been also usefully applied as a means of scientific research and the fusion of rare and untractable metals in small fragments (166). Valuable approaches have been also made in the application of the heat and light evolved by charcoal points to the lighting of streets and public buildings, based upon the experiments before given (119), (166).

247. Finally, we have to notice the application of galvanic electricity to the cure of disease, from which, considering the great chemical and other extraordinary powers of the voltaic apparatus, we should expect to derive most important consequences. In this application of the pile, however, we have certainly not as yet obtained that marked success which might be reasonably anticipated. Both common and voltaic electricity appear to possess no specific power as

medical agents beyond that of local or general stimulants. If the voltaic current could be directly applied to the excitation of nervous power (134), it is certainly possible that, under judicious management, some advantage may result, more especially in cases of suspended animation, as already observed (136); and it is, perhaps, more than probable that future researches may yet develop methods of application of this agency in the mitigation or cure of diseases as yet little contemplated. The present modes of application consist principally either in the direct action of the ordinary battery, as before explained (135), or otherwise in the operation of secondary action through the instrumentality of coil machines (222), which are so contrived as to regulate the power of the current force to any required degree, and for which Hearder's medical machine (222) is especially adapted. We are thus enabled to transmit current action between any two given points of the surface of the animal body, in the direction of certain nerves or muscles, or in the direction of the organs more especially connected with existence. As already stated, however, we have as yet to encounter a most patient and energetic course of experimental inquiry before we can hope to derive much real advantage from voltaic electricity as a medical agent.

THE END.

BRADBURY AND EVANS, PRINTERS, WHITEFRIARS.